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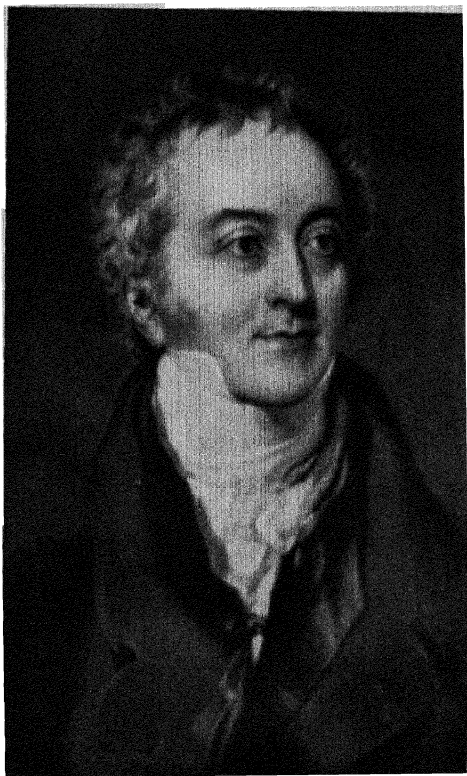
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THOMAS YOUNG, F.R.S.



THOMAS YOUNG M.D., F.R.S.

THOMAS YOUNG, F.R.S.

Philosopher and Physician

BY

FRANK OLDHAM, M.A., B.Sc., A.INST.P.

FORMERLY SCHOLAR OF ST. JOHN'S COLLEGE, CAMBRIDGE

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FOREWORD

By H. LOWERY, M.ED., PH.D., F.INST.P.

HEAD OF THE DEPARTMENT OF PURE AND APPLIED PHYSICS, COLLEGE
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THE publication of this volume on the life of Thomas Young requires no justification, since it contains all that is requisite for an instructive and inspiring biography.

Mr. Oldham has here presented a detailed account of the career of a great scientific worthy, together with a comprehensive survey, in non-technical language, of his varied achievements, the whole constituting a fascinating chapter in the history of science. Young was, however, not the specialized type of scientific worker with whom we are so familiar to-day. He had great literary gifts and extended his activities into diverse branches of knowledge. In consequence his biography will be read with keen interest by all those who are interested in literature, educational theory, medicine and physical science.

PREFACE

THE following pages seek to give a concise account of the life and work of one who was both a scientist and a philosopher. By the range and nature of his intellectual interests, by the methods of exposition which he employs, Dr. Young belongs to the eighteenth century; by the discoveries which he made known in early years of the nineteenth century he is a link between the eminent scientists of his own age and those of our own. As a student and medical practitioner relating his impressions of contemporary life at home and abroad, as one of the first scientists to lecture at the Royal Institution, as a publicist whose ideas were often challenged in his own day, Thomas Young always commands our interest as a humanist working disinterestedly in the cause of truth.

The present volume is the outcome of a suggestion made by Lord Rutherford during one of his lectures in the Cavendish Laboratory. It is to this suggestion and to the friendly encouragement of Dr. Lowery of the Manchester College of Technology that this monograph owes its existence. I take this opportunity of acknowledging my indebtedness to them and of expressing my best thanks to Mr. A. Hyslop, M.A., for his many valuable suggestions, to Mr. F. P. Dunn of the firm of Edward Arnold & Co., for his most helpful advice, and to Mr. H. P. Stout for his assistance in compiling the index.

F. O.

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THOMAS YOUNG, F.R.S.

PART I

LIFE

CHAPTER I

EARLY YEARS—THE CHILD PRODIGY

DR. THOMAS YOUNG, the greatest natural philosopher, or, as the French say, physicist, of the early nineteenth century, was born at Milverton, near Taunton, Somersetshire, on the 13th of June, 1773. His parents were Quakers, and to their example and training he doubtless owed much of the quiet dignity and reserve which characterized him in later life. From his earliest years he showed himself to be an unusually precocious child. He could read at the age of two, and knew the "Deserted Village" by heart before he was six. Most of his time at this period was spent at Minehead with his mother's father, Robert Davis, who was a merchant there, and was noted for his intellectual pursuits. His daughter, Mary Davis, had married a Mr. Thompson, a schoolmaster, and in March, 1782, Thomas Young became a pupil of his at the Compton School, Dorsetshire. The intermediate two years had been

spent with large intervals of absence at a school at Bristol, where he fared badly, the master being morose and incapable. At Compton progress was much better and he was helped considerably by the usher of the school, Mr. Jeffery. He read widely, particularly classical authors such as Virgil, Homer, Cicero and Xenophon; mathematics, the philosophy of Newton, a compendium of Oriental literature, and a little Hebrew. Besides the purely studious activities mentioned above, the usher taught him such useful practical arts as bookbinding, colour-mixing and copperplate making, which were to be of great service to him in later years. In the vacations, which he usually spent at Minehead with his grandfather, he came under the influence of a saddler named Atkins, who collected data of the barometric pressure, daily temperature and wind direction for the year 1782. This forerunner of our present meteorologists taught him the simple rules of measurement, and we find Young using his quadrant to measure the height of the hills in the neighbourhood. At the same time he took pleasure in such mechanical arts as lathe-turning and lens-grinding, and he constructed his own microscope to assist his studies in botany. He read Benjamin Martin's description of the microscope for help, and it was a reference in this book that led to his study of the calculus and his subsequent contributions to advanced mathematical physics. On leaving school he immediately applied himself to the study of the grammar of such languages as Hebrew, Chaldee, Syriac, Samaritan and Persian.

The next five years was a period of great progress

under a tutor of the name of Hodgkin. The latter was a well-known classical scholar, and Young received a ground-work in classics such as few are privileged to obtain. He was fortunate, too, in having as his fellow-student a boy named Hudson Gurney. The two became firm friends.

The record kept by Young of his studies at this time shows them to have been typical, apart from one or two small exceptions, of the course covered in a modern syllabus of classical studies at any one of our great schools.

At the same time he made considerable progress in French and mathematics, particularly Euclid and the conic sections. At the age of seventeen he had mastered the *Principia* and *Optics* of Newton, Linnaeus's *Botany*, the systems of Chemistry of Lavoisier and Nicholson; he was familiar with the works of Milton, Shakespeare and Burke, and rendered considerable portions of Shakespeare in Greek. His formation of foreign characters in writing was specially good, and equalled that of the celebrated Greek scholar Porson. Much progress, too, had been made in foreign languages; he knew his Corneille and his Racine, and made criticisms in French and Italian of French and Italian authors.

It was during these years, 1788-92, that he came under the notice of his great-uncle, Dr. Brocklesby, a well-known physician practising in the metropolis and an important figure in the chief literary and scientific circles of the day. We find the doctor advising his nephew in matters of health and encouraging him to send him his translations of Shakespeare into Greek, which he promptly showed

to Burke. This led to his being brought into touch with Porson, jottings from whose conversations were carefully recorded in the diary of the eager youth.

The broad general education of Young's early years was now to be replaced by the specific training required for the specialist. The training of those early years in languages, mathematics and science had given him knowledge and understanding upon which he could build and add his share when the time came. In particular the careful study of Greek and the practice he made of accurate penmanship was responsible for the ease with which he could copy hieroglyphics, which assisted him greatly in interpreting them. Careful observation and his practical nature were also responsible for his discoveries in science. Dr. Young is an outstanding example of a man whose classical training had not warped the appeal of natural phenomena and their scientific explanation. In fact, it can be safely stated that his classical training greatly assisted his scientific bent. On the other hand, his education suffered because he missed the moulding influence of other minds such as higher education in schools would give. Throughout his life he failed to talk down to the intellectual level of his audience when lecturing, and was never a success as a teacher. This followed from his inability to realize the difficulties which, though obscure and insuperable to others, were absent in his vision of a problem. His writings suffered likewise, and to such an extent that some of his brilliant discoveries were misunderstood for half a century. The best illustration comes from the mathematical arguments and methods in his various

publications, where much that was obvious to him must be puzzled out by his less fortunate followers. A further difficulty arose because he preferred the more clumsy Newtonian fluxions to the clearer and more concise French methods in the calculus.

CHAPTER II

MEDICAL EDUCATION IN LONDON

THOMAS YOUNG decided to train for a medical degree and entered as a student at St. Bartholomew's Hospital in September, 1793. This step was due to the advice and wishes of Dr. Brocklesby, who wanted him to carry on the extensive practice he had built up in the metropolis. Thanks to the extensive notes he made, we have detailed accounts as to the method of training and those responsible for the course. Medicine has changed completely during the last century, but the germ of the modern method is distinctly recognizable. He experienced the usual sound training in anatomy and physiology, the practice of physic, midwifery and botany. The method by which he approached his subject may be judged by the results of the dissection of the eye—a regular procedure in the course. He was given the eye of an ox recently killed, and found the ciliary muscles attached to the lens still active and by their responses compressing the lens of the eye. This gave him a clue to the explanation of "accommodation" of the eye by which we are able to see objects clearly though they are at different distances. The eye must, therefore, be different from an ordinary glass lens such as would be found in a camera, and it is a well-known fact that if we want an image

clearly focused on the film or plate of a camera, we must move the lens forward or backward. Young's medical contemporaries believed that in men and in animals the eyeball itself was elongated when near objects are viewed so as to get the lens of the eye at the appropriate distance from the retina. This was disputed by Young, who drew attention to the ciliary muscles and argued that their action on the circumference of the lens produced a greater bulging or curvature which caused a decrease in the focal length. The net result would be to bring the image nearer to the lens and soon to the retina. The theory was published in the *Royal Society Transactions* of 1793, and secured the author's election to a Fellowship of the Royal Society at the early age of twenty-one. The paper, however, raised a great deal of controversy, and it was not until 1800, when Young took up the matter again, that the opponents of the theory were finally routed. We shall return to a discussion of this important contribution to the science of optics in a subsequent chapter.

There are some interesting records of Young's vacations in the year of his election to the Royal Society. He visited Somersetshire, and went on to Devon and Cornwall, accompanied by Hudson Gurney. The chief items of interest reported upon were the botany and geology of this part of Britain. Whilst he was in Bath, Young called on one of his uncle's patients, the Duke of Richmond, and so impressed was the latter by the dignified and unaffected bearing of the young Quaker, as well as by his wide knowledge of the humanities and science, that he offered to make him his private secretary. This

was a position of great importance, particularly to anyone aspiring to political life; moreover, his duties would have been mainly of a scientific nature, because the Duke, as Master-General of Ordnance, was interested in trigonometrical surveying. Young decided to refuse the offer, partly from his religious views, and partly because he still adhered to his original intention of becoming a medical practitioner.

CHAPTER III

SCOTTISH EXPERIENCES AND EDINBURGH UNIVERSITY

IN the autumn of 1794 Young decided to continue his preparation for a medical degree at Edinburgh, and he proceeded northwards quite leisurely, visiting places of scientific and general interest. Thus he records the hospitality of Bakewell, of Dishley Grange, Leicestershire, who had succeeded in improving the cattle and sheep of his farm by cross-breeding. It was one of the first attempts in this country to produce an animal suitable for certain definite purposes, say wool or meat only. The method has been so successful that it has been adopted all over the globe. Young also refers to Bakewell's system of irrigation and the practice of regular cropping of grass which was given to stalled cattle, since if the latter graze they tend to spoil the grass.

Next there is mentioned a visit to Erasmus Darwin, the father of the celebrated Charles Darwin, who was a very hearty old man with unorthodox medical views and a gift for art, poetry and philosophy.

At Edinburgh he found a delightful atmosphere of friendliness, particularly since his fame as a classical scholar had gone before him, and a number of letters of introduction to the best society of the city

completed what was required for the beginning of his social development. The department of medicine was in a flourishing condition under the able guidance of Drs. Gregory, Monroe and Black. The last-named is particularly well known for his work on the subject of *Heat*, as well as for his contributions to chemistry, and it is certain that Young derived a great deal of benefit from the methods employed by the Edinburgh School. It was at this stage of his career that he decided to increase his knowledge of contemporary art and literature; he took a new interest in drama, music and dancing, a result no doubt of the wider interests of the new society in which he moved. Although he still adhered most strongly to the tenets of his particular creed, he found the visits to the plays and his lessons in dancing a little too revolutionary for the Quakers, and it served to alienate him from their society. Of their main principles, however, their love of peace and order, their high standard of moral conduct, Young remained the strictest observer all his life.

Professor Dalzel, who held the Greek Chair in the University, was very intimate with Young, who assisted him in compiling an *Anthology of the Greek Poets*, a book which was used considerably in the last century. Young contributed the selection from the Greek epigrammists and added notes.

Not content with tasks of this kind, he read very widely in German, Spanish and Italian, and also studied some of the works of Dr. Johnson. The latter had published some thirty years previously a *Tour of Scotland*, and as Young proposed a similar

journey, it is interesting to compare their impressions. Johnson writes very disparagingly of the Scots, but pays great tribute to the beauties of scenery; Young speaks highly of the people, but makes no reference to those beauty-spots for which the country is noted. He informs us of the nature of his equipment—

“A stout black horse fourteen hands high, young and spirited—I had before me my oiled linens; under me a pair of saddle-bags, well filled with three or four changes of linen, a waistcoat and breeches, materials for writing; soap, brushes and razor; a small edition of Thomson’s *Seasons*, a third flute in a bag, some music; a box for botanising; a thermometer; two little bottles for preserving insects; a bag for picking up stones and two maps of Scotland.”

Letters of introduction to about fifty people residing at various points on the route indicate the thorough manner in which he proposed to see the land. The route embraced Stirling, St. Andrews, Perth, Blair to Braemar *via* the pass of Glen Tilt, Arbroath and Aberdeen. The hardships of the journey, which would be very agreeable to many of the present day, he considers to be relieved by the hospitality he received wherever he went. At St. Andrews he met Professor Hunter, who showed him the library, which, though entitled to a copy of every book entered at Stationers’ Hall, was increased by subscriptions from the students. The average annual cost “for fees, board and lodging” was about £16, which indicates the difference in the cost of living from that of the present day. Aberdeen then possessed two Universities (King’s College and Marischal College), illustrating the

keenness with which the Scots regarded education. Young writes very favourably of Professor Copeland of Marischal College, who was a competent experimental physicist and delighted him with various pieces of home-made apparatus designed to illustrate the various parts of the subject. Young was obviously impressed, for he adopted the same method when he became a lecturer at the Royal Institution.

After reaching John o' Groats *via* Inverness and Wick, he returned to Elgin, and stayed for a few days at Gordon Castle, Fochabers, the home of the Duke and Duchess of Elgin. They were related to the Duke of Richmond, and Young has given a graphic description of the visit, which helps us to view their mode of life. When he arrived, a party was in progress, and after a moderate time spent in drinking, the men joined the ladies, who were dancing. This was the occasion for all to join in dancing reels, in which Young appears to have been accomplished. Next morning the Duke took him to see his workshops and showed him apparatus for the pursuit of science mostly made by himself under Professor Copeland's direction. They went out to hunt deer, but were unfortunate in returning without any bag. In the evening Young took out his diary and read some of his work in the classics, and the attention and alertness of his audience convinced him of the family's intellectual acuity. The following day he spent visiting the grounds and was much impressed by the fine trees which dated back to the time when Scotland was all forest. Later he was entertained by the Duchess, who gave an account of her studies and presented him with a copy of

Petrarch. The day happened to be her daughter's birthday; there were games and racing for the youngsters in the afternoon, and a ball for the servants in the evening. Young tells us how all the servants were descended from previous retainers and considered their vocations as practically hereditary. His enjoyment was such that he confessed in his journal that he "could almost have wished to break or dislocate a limb by chance, which would necessitate his being detained." Duty called him south, for it was decided that he should go to Germany for further study. He had time to traverse the Caledonian Canal, or Glen More, as it was then called, and visited Staffa, the geological formation of which had recently been brought into prominence by Sir Joseph Banks. An account of a brief stay at Inveraray Castle, the residence of the Duke of Argyll, and shorter notes on the Lakes, Liverpool, and the iron-works at Coalbrookdale, near Shrewsbury, conclude his description of this interesting tour. He now prepared for his stay in Germany, for his uncle was convinced that a course of study at Göttingen would be of inestimable benefit to any student of medicine.

CHAPTER IV

GÖTTINGEN UNIVERSITY AND EXPERIENCES IN GERMANY

YOUNG's experiences in Germany afford an illuminating account of the state of the country at that time. The year 1796 was memorable in many ways, for the French nation, having outgrown the "Terror," became reorganized and adopted an aggressive attitude towards the neighbouring countries. This controlled Young's original plan. He had intended to spend eight months at Göttingen and then to tour Switzerland, Austria and parts of Italy. The scheme was not carried out in full, but he did travel widely over Germany.

In October, 1795, he crossed from Yarmouth to Hamburg, a route necessitated by the French war. He travelled in the Stuhlwagen *via* Hanover to Göttingen. This conveyance corresponded to the English stage-coach, but was fitted with curtains instead of glass windows. Some impression of the state of the roads may be gathered from the fact that two nights and part of two days were spent in covering the ninety miles to Hanover. After another day's journey he reached Göttingen and put up at a house belonging to a Professor Arnemann, who was a Doctor of Medicine. Judging from his writings, he appears to have concentrated on social accom-

plishments more than on his medical studies, though with his characteristic energy he read far more than the average student. The following details from his journal give us a good illustration of a typical working day:

"At 8, I attend Spittler's course on the History of the Principal States of Europe, exclusive of Germany." "At 9, Arnemann on Materia Medica." "At 10, Richter on Acute Diseases." "At 11, Twice a week, private lessons from Blessman, the academical dancing master." "At 12, I dine at Ruhlander's *table d'hôte*." "At 1, Twice a week, lessons on the Clavichord from Forkel, and twice a week at home from Fiorillo on Drawing." "At 2, Lichtenberg on Physics." "At 3, I ride in the academical *manège*, under the instruction of Ayer, four times a week." "At 4, Stromeyer on Diseases." "At 5, Blumenbach on Natural History." "At 6, Twice Blessman with other pupils, and twice Forkel."

Glimpses of Young's social activities are also to be found in his correspondence. Every Saturday a musical concert was given by the students. Sundays were set apart for social events, and professors received students. All enjoyed entertainments of one sort and another. Young notes, among other things, an absence of that hospitality and freedom which he observed in Edinburgh. The few young ladies were very closely guarded, as parents were apt to fear a traitor in the heart of every young man. This Young deplotes, and for very sound reasons:

"I wish I was more acquainted with some of them for the sake of exercise in the language; for conversation with women gives a fluency of expression and a delicacy of manners which are never to be learned from men."

We must not, however, conclude that Young's social activities were unduly restricted. On the contrary, he had quite a busy time, all the more so because he wanted to be at ease in all personal contacts which many learn naturally from their youth upwards, but which he missed from the nature of his early isolation.

Young was greatly impressed with German medicine and science, for in contradicting some of his uncle's opinions on these subjects he emphasizes the fact that the Germans know their own authors as well as those in London, but the reverse did not hold. After a six months' stay he took his examination. The account he gives is amusingly described as follows:

"I made no preparatory study, as is usual here and also at Edinburgh not uncommon, under the name of grinding. The examination lasted between four and five hours; the four examiners were seated round a table, well furnished with cakes, sweetmeats and wines, which helped to pass the time agreeably; the questions were well calculated to test the student's knowledge in practical physic, surgery, anatomy, chemistry, materia medica and physiology; but the professors were not very severe in exacting accurate answers. Most of them were pleased to express their approbation of my replies. We were all previously obliged to give a summary account of the manner in which our lives had been spent."

Young also submitted to his examiners a Latin dissertation, "*De Corporis Humani viribus conservatricibus.*" He also read a short paper on the human voice in the summer Auditorium, and after offering something like a prayer, was married to Hygeia and made a Doctor of Physic, Surgery and

Man-midwifery. In the paper he drew up an alphabet of forty-seven letters, designed to express by their combination every sound the human voice utters; this alphabet, he claimed, would be of great use in the study of languages hitherto unwritten, as for instance the tribal languages of Africa or America.

Young next made a tour of the Harz mountains, in the company of Leslie, who became famous for his researches in the subject of heat. Later on he visited Brunswick, Jena, Leipsic, Dresden and Berlin, returning thence to Hamburg. At Brunswick he was introduced to the Court circle.

“I was presented,” he says, “to the duchess (our King’s sister), to the hereditary princess, the Stadtholder’s daughter, and the duchess dowager, sister of the late King of Prussia. The duchess and princess each talked about two minutes with me. The mother asked me two questions, and from this time till nine I was left at my own disposal . . . I was glad when supper was announced; about twenty ladies sat on one side of the table, and as many gentlemen on the other; I was placed in the middle opposite the princess: the duchess was not there. I attempted to converse with one of my neighbours, but he was either stupid or sulky, and the others were engaged among themselves. At last the duchess dowager—who looks like a spectre—has lost her teeth—and whom I fancied totally unfit for all company, began a long and amusing conversation. She asked me what I had studied at Göttingen. I told her I was a doctor of physic. If I could feel a pulse: how frequent the most rapid pulse that I had felt was: whether the English or the Germans had the best pulses. I said that I had felt but one pulse in Germany, which was that of a young lady and was a very good pulse. She asked me if there was a good theatre

of anatomy at Göttingen. I told her, pretty good, but that I did not attend it; I had only gone to a single lecture, and seen the professor dance a caricature dance; that I had been a more frequent attendant at the *manège* than the school of anatomy. Our discourse awoke the attention of those who were within hearing, and now I had enough to talk with; but supper was soon over, and the company dispersed.

"On the following morning I went to see the ducal *manège*; the horses are good, but the riding must not be compared with Göttingen."

Young was an expert at horsemanship and in Germany was known by the students more for this athletic prowess than for his writing of Greek. In his tour he managed to pass through Freiburg, where he reports at length on the extraction of silver by mercury—a good source of revenue to the Elector of Saxony.

Travelling, however, was difficult at this stage, for many emigrants of the lower type had turned to brigandage. The advance of the French caused his return to Hamburg on the 14th of January, 1797, and after a wait of several days at Cuxhaven for permissible sailing weather, arrived at Yarmouth in the beginning of February.

Young's impressions of other sides of German life and thought are not without their interest to modern readers. Writing of Kant, he says:

"Kant in point of popularity is more than the Aristotle of Germany. In his life-time he makes already the text of numberless commentators; and it is as much of a compliment to say of a man that he is a good Kantian as that he is a good Grecian. I therefore thought it necessary to have at least an acquaintance with his principles, more from a

knowledge of their currency than from an opinion of their worth; and I have not yet been able to see them in a better light. From what I have read of his works, Kant seems to possess great penetration, yet not without confusion of ideas. His language is unpardonably obscure; it is also one of the spurious arts of becoming popular to affect innovations in language. His system may, perhaps, be shortly described by saying that it is diametrically opposed to Hume's."

"Thus we realize," says Dean Peacock, in commenting on this passage, "that Young's mind was essentially English."

Concerning authors and publishers, Young adds:

"In the learned world the great majority are mere mechanical labourers; the names of a Schiller, a Wieland, and a Göthe are but rare luminaries among an infinite number of twinkling stars and obscure nebulae. The established custom of the booksellers, who pay every ordinary writer exactly in proportion to the number of sheets, and at their periodical fairs exchange bulk for bulk of every kind of publication, is the grand impediment,—among those who are necessitated to subsist in part by writing,—to the laconic effects of a brilliant genius, and the cause that the innumerable and ever-increasing heap of volumes envelops from day to day more and more sciences which it is designed to illustrate."

Young deplored the number of independent states and preferred a single metropolis such as London to a large number of provincial capitals. His opinion on the evil effects of such decentralization are illustrated again and again in his correspondence:

"The pride of independence in the petty states is the cause of the great existing number of universities, all furn-

ished with numerous professors, who are generally ill-paid by the institutions, and to increase their fame and fill their purses are tempted to undertake an unreasonable diversity of lectures, which their diligence raises to the merit of minute prolixity, but which their genius seldom elevates above the rank of mediocrity. The students from diligence or vanity, as well as from universal custom, are prompted to attend to a superficial course of study in every imaginable subject of literary information which they take implicitly from the tribunal of the school, retain in some shape by a mechanical memory, until time and other pursuits,—unless fortunate circumstances have favoured them—wash out those slight impressions, which, if infixed, would have been both ornamental and useful. Hence one advantage of the usual education in England, however grossly deficient it may be in some particulars; the ancient languages are generally so impressed as never to be entirely forgotten, and having attained a considerable degree of perfection in any one branch, the influence of this positive acquirement may extend into the remotest pursuits.

“There are many points in which Germany differs from England that almost baffle all description. Whether the human mind is in a more cultivated state in this or that country, is very difficult to say: there are more learned men in Germany than in England, but we have and ever have had some individuals in many branches who are almost unequalled. In the Mathematics and in Chemistry the Germans are making rapid advances; as painters they copy better than the English, but have perhaps less invention; in engraving the English confessedly excel them; and the Germans still more decidedly bear away the palm in music in which they rival the Italians.

“The great number of independent states reduces the courts more nearly to the resemblance of private companies than elsewhere; it is usual for all those to be introduced who have a title to that privilege, and this keeps up a marked

distinction between the numerous and poor nobility, and the richest or most accomplished of the commonality; and even a nobleman of late creation is not admitted into the first circles at Vienna, nor permitted to dine with the Elector of Saxony.

"The ornamental exercises, especially among the nobility, are more attended to than in England; riding, fencing, vaulting and dancing; the prevalence of a military life is also in part a cause of this, as well as of some other differences. The union of literature and fashionable elegance is very rare; the learned never aspire to make a figure in the gay or in the political world; and those in power look upon a man of letters at best merely as an ornament to their court, like a musician or dancer.

"The laws in most parts are guided by the Roman Civil Law; the depositions taken in writing, and the sentences given in private. The physic is composed of that of all other nations; for they read of all books in all languages, but they select too little and do not appear to know the meaning of simplicity. Scarcely a work of any consequence can appear in any country, but that one or more translations of it are immediately promised. The Germans have sometimes been accused of too great an attachment to the imitation of foreigners; their Anglomania in physic has of late been rather too rashly censured.

"The German language is easily so far learnt by an Englishman, that he can read a common author, but the connection of sentences and the order of words is so intricate that it is difficult to speak and write it with perfect delicacy. It is capable, by the facility with which it admits of all manner of combinations, of expressing readily many compound ideas which can less easily be rendered into any other language: some of its guttural sounds, and some combinations of consonants, are rather unpleasant to the ear, but the general tenor of the language is sufficiently soft, and the accent and cadence diversified, and, at least to an English

ear, agreeable. It has more dignity than the French, and more force than the Italian; I think it has a vigour of expression hardly equalled by any other language; but such a comparison is very difficult to make. Hanover and Göttingen seem to be the nearest to correctness in their pronunciation, but this varies widely all over the country.

“What impressions a stranger would receive from France and Italy, I cannot judge; but I should think Germany at present the most interesting country to a traveller of any in Europe; not so much from its original merit, but from its being a kind of compendium of everything that is excellent, and everything that is remarkable in every country existing; nor do I in the least repent the time and labour employed in seeing and learning as much of it as circumstances would allow me.”

These statements of Dr. Young, written in 1797, are of great interest in that they help us to compare Germany and England to-day with their state nearly a century and a half ago. We already see a sympathetic and shrewd observer of Europeans in the man who was to become Foreign Secretary of the Royal Society.

CHAPTER V

THOMAS YOUNG AT CAMBRIDGE UNIVERSITY

YOUNG's previous medical education had been confined to one year's residence, at London, Edinburgh, and Göttingen respectively, but the College of Physicians would only recognize two consecutive years at the same University for an award of their degree, and it was to comply with this regulation that he entered Emmanuel College, Cambridge, in October, 1797.

Most students entered Cambridge at the age of nineteen, so that Young would be five years above the average age for admittance. This, together with his previous scholastic attainments, would hardly help him to mix well with the undergraduates. The graduates, on the other hand, were in the none too enviable position of having a pupil more able to give than to receive instruction. Young's good sense avoided the friction which might have arisen in one less tactful and ambitious, and he enjoyed a quiet uninterrupted series of terms. There was no course in Medicine recognized by the Senate, although general lectures in anatomy suitable for all were given by that able exponent, Sir Busick Harwood, and these Young attended. The President of Emmanuel was a friend of Dr. Brocklesby,

and Young was introduced to the Fellows and Dons of that college, and through this introduction became fairly well known to those of other colleges. The younger students tended to avoid him, and dubbed him "Phenomenon Young," which pays him the compliment of being distinguished as a genius, and savours of sour grapes.

The regulations for the undergraduates were so formed that in spite of high spirits and freedom a certain amount of control was possible, and the change from a rigorous school system was not therefore too abrupt for those likely to abuse their new freedom. To one of Young's age they might have been irksome, but he only complained of the cold and distant manner which some of the graduates affected.

It may be safely estimated that his studies at Cambridge were extremely profitable, for he was enabled to devote time to complete his work on the eye as an optical instrument, and begin those researches on the intimate nature of Sound and Light, which subsequently placed him in the foremost rank among the scientists of his day. Moreover, the number of pupils was limited, so that the instruction was almost tutorial and he could follow to a logical conclusion any particular problem arising during his hospital and anatomical courses.

One of his contemporaries writing of him includes the following remarks:

"He had a high character for classical learning before he came to Cambridge; but I believe he did not pursue his classical studies in the latter part of his life—he seldom spoke of them; but I remember his meeting Dr. Parr in the college

Combination room, and when the Doctor had made, as was not unusual with him, some dogmatical observation on a point of scholarship, Young said firmly, 'Bentley, sir, was of a different opinion'; immediately quoting his authority, and showing his intimate knowledge of the subject. Parr said nothing, but when Dr. Young retired, asked who he was, and though he did not seem to have heard his name before, he said, 'A smart young man, that.'

"The views, objects, character and acquirements of our mathematicians were very different then from what they are now, and Young, who was certainly beforehand with the world, perceived their defects. Certain it is, that he looked down upon the science and would not cultivate the acquaintance of any of our philosophers.

"He did not seem even to have heard of the names of most of our poets, or literary characters in the last century, and hardly ever spoke of English Literature.

"He never obtruded his various learning in conversation; but if appealed to on the most difficult subject, he answered in a quick, flippant, decisive way, as if he was speaking of the most easy; and in this mode of talking he differed from all the clever men that I ever saw. His reply never seemed to have cost him an effort, and he did not think there was any credit in being able to make it. He did not assert any superiority, or seem to suppose that he possessed it; but he spoke as if he took it for granted that we all understood the matter as well as he did. He never spoke in praise of any of the writers of his day, even in his own peculiar department, and could not be persuaded to discuss their merits. He was never personal; he would speak of knowledge in itself, of what was known or what might be known, but never of himself or any other, as having discovered anything, or as likely to do so.

"His language was correct, his utterance rapid, and his sentences, though without any affectation, never left unfinished. But his words were not those in familiar use,

and the arrangement of his ideas seldom the same as those he conversed with. He was, therefore, worse calculated than any man I ever knew for the communication of knowledge. I remember his taking me with him to the Royal Institution, to hear him lecture to a number of silly women and dilettanti philosophers. But nothing could show less judgment than the method he adopted; for he presumed, like many other lecturers and teachers, on the knowledge and not the ignorance of his hearers.

"In his manners he had something of the Quaker remaining; and though he never said or did a rude thing, he never made use of any of the forms of politeness. Not that he avoided them through affectation; his behaviour was natural without timidity, and easy without boldness.

"It was difficult to say how he employed himself; he read little, and though he had access to the college and university libraries, he was seldom seen in them. There were no books piled on his floor, no papers scattered on his table, and his room had all the appearance of belonging to an idle man. *I once found him blowing smoke through long tubes*, and I afterwards saw a representation of the effect in the *Transactions of the Royal Society* to illustrate one of his papers on sound; but he was not in the habit of making experiments. He walked little and rode less, but having learnt to ride the great horse abroad, he used to pace round Parker's Piece on a hackney.

"He seldom gave an opinion, and never volunteered one. He never laid down the law like other learned Doctors, or uttered apothegms, or sayings to be remembered. Indeed, like most mathematicians (though we hear of abstract mathematics), he never seemed to think abstractedly. A philosophical fact, a difficult calculation, an ingenious instrument, or a new invention, would engage his attention; but he never spoke of morals, of metaphysics, or of religion. Of the last I never heard him say a word, nothing of any sect, or in opposition to any doctrine; at the same time, no scept-

tical doubt, no loose assertion, no idle scoff ever escaped him."

These remarks indicate the kind of man Young appeared superficially to his intellectual contemporaries, and we further deduce that the writer was unable to appreciate Dr. Young as a natural philosopher. This is not to be wondered at, for the value of most of his work was not recognized until after his death. It is amusing to read of the experiment of blowing smoke through long tubes—it is often the simplest and, to the uninitiated, trivial appearances which contain the germs of new and epoch-making discoveries.

At the end of the Michaelmas Term, 1797, his uncle, Dr. Brocklesby, died and bequeathed Young his house in London and a fortune of about £10,000. For two years following we find very little information of his pursuits, during term or on vacation, although when confined to his home by reason of an accident, he does refer to an entry into contemporary mathematics of Lagrange and Laplace and goes on to pay tribute to the neatness and elegance of their methods, as compared with those of the English School.

Thomas Young completed his number of terms' residence at Cambridge by the end of 1799 and immediately moved to London, where he resided at 48 Welbeck Street. According to the statutes of the University, he was unable to receive his M.B. until 1803, and a further five years had to elapse before he could be granted the degree of M.D. Naturally a junior medical man could not be ex-

pected to have so large a practice as that which his uncle enjoyed, and Young found much enforced leisure. This he turned to good account, as shall appear in a subsequent chapter.

CHAPTER VI

THE ROYAL INSTITUTION APPOINTMENT

At the opening of the nineteenth century the Royal Institution was barely a year old, and like a sickly infant showed little promise of reaching maturity. Among those most active in superintending its establishment was Benjamin Thompson, better known as Count Rumford, a short biography of whom figures in the works of Thomas Young. A soldier by profession, he was in the service of the Elector of Bavaria from 1784 to 1798. His reorganization of the police of the Bavarian capital and his many schemes of civic improvement attracted wide attention. His success was recognized by the Elector, who created him a Count of the Holy Roman Empire. From 1798 to 1801 he lived in London and devoted himself wholeheartedly to the development of the Royal Institution. He left England for Paris in 1802 and later (1805) married Madame Lavoisier, after which he seems to have taken no further interest in the Royal Institution. He died in 1814. So persuaded was he of the value of applied science that in winter he wore a white hat and coat because his experiments indicated that black substances radiated more than others.

The original purpose of the Directors of the

Institution was that of applying science to the conveniences and comforts of civil and domestic life, and furthermore of making it serve as a medium for introducing the subject to craftsmen and artisans—carpenters, saddlers and metal-workers who might otherwise remain in ignorance. Rumford was the very man for this purpose, and he threw himself whole-heartedly into the enterprise. He wanted it to be a model for similar schemes the world over, but found the idea would not work—artisans and professors could not agree. Rumford had secured the services of Dr. Garnett, who was well known both for his knowledge of medicine and chemistry as well as his powers of lecturing to the public. Garnett was suffering from ill-health and was not successful, and he was soon replaced by Humphry Davy, who completely altered the design and scope of the Institution. He planned a great scientific club, which should be the meeting-ground of society. Fashionable society, it will be remembered, loved to dabble in science in those days, and George III himself had his own private laboratory. Davy's lecture on January 21st, 1802, advanced these objects and dwelt emphatically on the worth of science as an agent in the improvement of society. Davy had magnificent zeal and a consummate delivery which won him good and increasing audiences. His reputation as poet and his friendship with Coleridge were also no doubt instrumental in making his lectures and the Royal Institution more widely known. Two adjacent houses in Albemarle Street, Piccadilly, were originally used by the Directors, but very soon they were converted into a club

with lecture rooms, model rooms, a library and secretary's rooms, and housing accommodation.

In the previous July, the Directors, of which Sir Joseph Banks, President of the Royal Society, was the chief, engaged Dr. Thomas Young as Professor of Natural Philosophy, editor of the Journals, and General Superintendent of the house. This last duty was important as Rumford had engaged a cook for the improvement of culinary arts, and Young would have to report on all expenses, lectures, and the improvements in domestic economy. It is usually held that the appointment was a failure, and that Young would have been better employed elsewhere. This view cannot be accepted, when all the evidence is assembled. Granted that he was no success as a lecturer, and that those basking in the sunshine of the witty, polished encomiums on science of the greater Davy were befogged and rendered gloomy by the frigid, austere and laconic Young, can we judge from the numbers attending the lectures or the verdict of those present? Nowadays the lectures given by Young form a storehouse of knowledge to which few can refer without improvement, while Davy's discourses are of little value. All the evidence supports the view that the world of science is indebted to the Directors of the Royal Institution for their appointment. The lectures must be read with care, perspicacity and patience, and in the capable hands of the late Lord Rayleigh truths were revealed which the careless, superficial and less accomplished devotee would have missed. Dr. Young lectured from January 20th, 1802, until May 17th, giving thirty-one lectures. It may be

assumed that he increased this number to sixty in the following year, whereupon it was resolved, "That Dr. Young be paid the balance of two years' complete salary, and that his engagement with the Institution terminate from this time, July 4th, 1803." This reads like dismissal, but on closer inquiry we find that Young's chief desire was to establish himself as a medical man, and as such he desired above all things to let nothing hinder him from realizing his aim.¹ The leisure of the next four years enabled him to revise his lectures, make considerable additions to them in the light of his further experiments and experience, while including an abstract of the most important contributions to Natural Philosophy up to his day. This great work was done during the spare time of his rise in the medical profession. After 1807, when he published this *Course of Lectures on Natural Philosophy and the Mechanical Arts*, he refrained from signing his name to any of his publications, other than medical, for a period of eleven years.

¹ See pp. 132, 133.

CHAPTER VII

DR. THOMAS YOUNG THE PHYSICIAN

THE first reference to be found of Dr. Young's work in a medical capacity is that of being summoned to accompany the nephews of the Duke of Richmond to France in 1802 during the Peace of Amiens. He did not qualify for the M.B. degree until the following year (March, 1803), so it was more the office of tutor and guardian than doctor.

From 1804 until 1820 Dr. Young made every effort to succeed in practice. He gave lectures in medicine at various hospitals in London, and during the summer months, July to September, he lived in Worthing, where he had a number of patients who spent the summer at this resort. The Napoleonic wars were responsible for the popularity of holidays on the South Coast of Britain, for travel on the Continent was out of the question.

A vacancy for a Physician at Middlesex Hospital occurred in May, 1807, but Dr. Young was an unsuccessful applicant. Later he was asked to give a course of lectures to students at the hospital, and this duty encouraged him to prepare a treatise on *Medical Literature and the Practice of Physic*. During this time he was becoming known as a promising physician, the wealth of his knowledge appearing in

his lectures having enhanced an important practice. In the following year (1808) he took the Cambridge degree of M.D. and presented a thesis in Latin on a medical subject. Shortly afterwards he was chosen to give the Croonian Lecture to the Royal Society, and for his subject took the Functions of the Heart and the Arteries. He was interested in the problem of the mechanical principles involved in the circulation of the blood, and it may be gathered that he was led to this research by taking the problem of inflammation of the arteries for his thesis.

Early in January, 1811, there happened to be a vacancy for a physician at St. George's Hospital. This post, which was held some years before by Dr. Hunter, the greatest of the physicians of Young's student days, was recognized as the prelude to a first practice in the Metropolis. Young secured the post by the narrow margin of eight votes, and was attached to the hospital for the remainder of his life, even after he had ceased practice. We have no knowledge of any great discovery he made in medicine nor of any outstanding cures, but according to Dr. Pettigrew and Dean Peacock, there is considerable evidence upon his methods and his attitude to the medicine of his times. He was not sympathetic towards *vigorous practice*, as it was called in those days. His treatment was more or less the type recommended to-day where those processes of restoration and cure are encouraged. The popular method then was the use of calomel, of the lancet and the leech. Symptoms were rudely interfered with and combated without any proper study of their

causes and the way they originated. Dr. Young's methods were very sound and as a practitioner he was generally successful in the number of patients relieved, but he was never popular. He was gifted with rare powers of observation, and an extensive and deep knowledge of his subject. He had patience and perseverance to succeed in experiment, and he was well known. He was not genial, however, and never expressed more than he felt, and lacked a good bedside manner. Finally, he was perhaps too diffident in forming a judgment or in offering an opinion on medical matters where others would find no difficulty. The very extent of his knowledge was in some measure a barrier between him and success as a popular physician.

Dr. Young's real talent lay elsewhere. It is as compiler, historian, and publicist that his name is honoured in the annals of medicine. A humanist and a scientist, he was never happier than when his wide knowledge was being used to advance the learning and prestige of the profession he had chosen. His *Preliminary Essay on the Study of Physic* (1813) insists on the value of a preliminary cultural training, on the necessity of the student's being able to specialize in any one branch of the subject, and on certain general qualities of mind and character essential to successful study and practice. The method of approach to medicine is, he claims, different from that of other subjects. Whilst the

“mathematician may arrive at the highest possible degree of eminence in the different modes of calculation without requiring any assistance from an accurate knowledge of

different languages and the linguist may be complete master of all subjects of grammar and criticism, without the slightest acquaintance with geometry: there are other branches of study so confined within themselves, and so capable of accurate deduction and precise definition, as to be completely independent of all others, and to require the exercise of a clear apprehension and correct memory only for their pursuit. Other departments, however, defy all attempts to subject them to a didactic method, and require the exercise of a peculiar address, a judgment or a taste, which can only be formed by indirect means. . . . Physic is one of these departments, in which there is frequent necessity for the exercise of an incommunicable faculty of judgment, and a sagacity which may be called transcendental, as extending beyond the simple combination of all that can be taught by precept."

Dr. Young claims that the science of medicine requires as much, if not more, penetrating intellect, genius and memory than any other study. Added to this are the necessary qualities of stable judgment, quickness of decision, and a cool firm presence of mind, with engaging manners and tact to deal with all types of mankind. Obviously anyone thinking of taking up medicine as a career would do well to find out whether he possesses these qualities, and the worthy professor states that as an individual is born with or without them "he should not dare to enter the temple of Hygeia, unless the distinguishing marks are evident." He goes on to say that no art except that of war requires so much courage, promptness in judgment and in action, as the art of physic. The feelings of the doctor must be kept under control, everything being subservient to the good of the patient, and on the whole

"the manners and behaviour must be decorous, polished, obsequious, courteous, gentle, obliging, cautious, and at the same time manly and dignified in every respect. To effect this his mind must be cultivated by the best education and by knowledge of mankind and of the world. Those persons, therefore, must never expect to acquire what is absolutely necessary for the practice of physic, much less to distinguish themselves by superior excellence, who are as deficient in the qualities of the mind as in moral culture and polished education, and who consequently have not learned, and who have not been accustomed, to accommodate themselves to the world and to individuals, to subdue their passion when it is required of them, to bear the burdens of their employment without repining, and to think and act uninfluenced by conceit, by caprice, and by senseless prejudices. Such persons as these, if, in spite of their deficiencies, they will still persist in the pursuit of physic, can only become, for want of talent, short-sighted, stupid, spiritless, superficial, useless and dangerous practitioners; and for want of good sense, and cultivation, affected, stiff, rough, quarrelsome, vainglorious, empty, presumptuous, proud and mean members of society; who can at best succeed with the lowest ranks of the populace only; who will necessarily expose to ridicule themselves and their profession, and who must perpetually shock the feelings of every refined and well-educated man."

Naturally, he continues, by adding that such qualities come only with growth and experience, but there must be definite evidence of these qualities in the student and they must be supported by a robust constitution. The preliminary education advocated by Young runs somewhat as follows:

- "At 2, 3, or 4 years of age, Reading and reciting English.
- „ 6 years of age, Latin and Writing.
- „ 8 „ „ „ Arithmetic.

At 10 years of age, Greek.

„ 12 „ „ „ French.

„ 14 „ „ „ Italian and Geometry.

„ 16 „ „ „ German, Mathematics.

„ 17 „ „ „ Natural Philosophy, Drawing.

„ 18 „ „ „ Chemistry, Botany.

And for studies more strictly medical:

First year: Anatomy. Theory of Medicine (Clinical Lectures). Continuation of Chemistry and Botany. Mineralogy.

Second year: Practical Anatomy. Physiology. Hospital. Practice of Physic.

Third year: Comparative Anatomy. Surgery. Midwifery. Materia Medica. Clinical Lectures.”

This early training should, according to Young, be supplemented by practical experience in some public appointment.

“An army physician,” he says, “has often considerable advantage, in acquiring both experience and emolument, at a time when he might otherwise be unemployed: but his experience is sometimes less appreciated in civil life, and in a different climate, than he has naturally been induced to expect it should be. The appointment of a physician to a hospital has so generally been considered as a very eligible introduction to practice, that it is scarcely necessary to mention it, except with a view to express a caution against overrating its advantages. A physician of the highest eminence has been heard to declare that he could never trace a single patient to his immediate connection with a well-known hospital, which subsisted for many years; and to give it as his opinion, that little less was to be learned by a diligent attendance of a hospital as a pupil, than by being employed as a physician to it. It appears to me that the most material

benefit to be derived from such an appointment, with regard to the extension of private practice, depends on the notoriety, that the physician must be unavoidably in the habit of prescribing continually for multiplicity of patients in all manner of diseases: but many have possessed this advantage, without obtaining the benefit in any material degree. At the same time few, if any, have ever risen to eminence without it, unless they have had some other very ostensible means of forming and supporting a general connection in a medical capacity."

The wisdom of such a course as Dr. Young prescribes is naturally debatable, especially the early preliminary education. Here we see very great prominence given to foreign languages, the young medical student having a smattering of five before he starts his life's work of medicine. A knowledge of French and German is essential in the ability it gives the student in reading publications in the original from the pen of European scientific and medical writers, but it is doubtful whether Greek and Italian would be accepted; the general opinion would be to omit their study for subjects such as history, geography and manual work. It is a characteristic of all educational practitioners prior to our own day to rely too much on the ability of a child to learn by heart, and to do little or no practical work. Again, it is recognized that the introduction of the child mind of ten years of age to Natural History followed by some of the purely experimental sciences in the following years is very helpful to a medical degree. The mathematicians, too, would disagree in leaving the introduction of their subject to the fourteenth year, many asserting that children from ten onwards

can secure a good grasp of geometry, algebra and trigonometry, so that at the age of sixteen the calculus may be entered upon advantageously. The actual course of medical study is usually spread over four to six years, and with the enormously improved medical facilities of the present day, it would be impossible to find a young physician without good practical experience.

No one more than Dr. Young was more anxious to enhance the prestige of his profession, and his equanimity was more than once disturbed by the contradictory opinion of eminent medical men.

"I was dining at the Duke of Richmond's one day last winter," he writes to a friend in 1806, "and there came in two notes, one from Sir Wm. Farquhar and the other from Dr. Hunter, in answer to the question whether or no his Grace might eat fruit pies or strawberries. *I trembled for the honour of the profession* and could not conceal my apprehensions from the company: luckily, however, they agreed tolerably well, the only difference of opinion being on the subject of the pie-crust."

This would certainly form a useful topic for discussion even to-day.

Contrary to the current opinions of the medical profession of his day, Young believed that the study of medicine could be advanced more satisfactorily and rapidly by a careful comparison of the collected observations of others than by the sole experience of a single practitioner. In a letter to a friend in January, 1807, he writes with reference to the appointment of Sir Humphry Davy to the office of Secretary of the Royal Society:

"If I had not been a member of an *illiberal* profession

I should have liked the situation myself; but perhaps the public is right in discouraging a divided attention. I purpose seriously to do something in physic, by collecting all that is worth knowing, and comparing it with the general economy of the operations of nature. I do not know who has attempted to do this soberly: Darwin had neither patience nor precision enough; and I am confident that much more may be learned and taught in this way than from a routine of old woman's practice, which is all that a fashionable practitioner obtains. In many other departments of science I have been able to draw conclusions from a comparison of the experiments of others, which I should have been much longer in discovering by investigations of my own; *and why not in physic.*"

The result of his researches was the publication of the *Introduction to Medical Literature*, the preface to which we have already noted. The author parted with the copyright for £100 in 1823 when the second edition appeared, and remarked that it was too good a book to be worth more. Other contributions to his subject were an Essay on Palpitations, a *Practical and Historical Essay on Consumptive Diseases*, and a translation from the Swedish of Berzelius's *Sketch of Animal Chemistry*. This latter work was all the more remarkable as Young was compelled to rely entirely on the use of a grammar and dictionary. Berzelius was impressed and gratefully acknowledged Young's effort:

"Tell me how it is possible for the same person to possess so deep and comprehensive a knowledge of two sciences so widely different as Natural Philosophy and Medicine, with its subordinate sciences of Anatomy and Physiology? When I reflect that Chemistry constitutes my only pursuit, and that nevertheless I am daily learning how much has been

done in that science that has escaped my inquiry, I marvel how you can have had time enough to go over all that you must have required to read in order to produce your Lectures on Natural Philosophy and this medical work."

A fitting tribute to the part played by Dr. Young in the diffusion and extension of medical knowledge is very ably summarized by Dr. Pettigrew in his Medical Portrait Gallery published in 1840. Speaking of the last of Young's medical publications, *A Practical and Historical Essay on Consumptive Diseases*, which appeared in 1815, he says:

"Dr. Young is not celebrated as a medical practitioner; nor did he enjoy an extensive practice; but in the information upon the subjects of his profession, in the depth of research into the history of diseases, and the opinions of all who have preceded him, it would be difficult to find his equal. His work on Consumptive Diseases is the evidence I would offer in support of this assertion. There is not an author of any note or celebrity—there is not a point connected with the disease which merits attention, that is not there most carefully, most accurately set forth. It is a medical library upon the subject of which it treats; the whole body of ancient and modern medicine in relation to consumption is included within the small compass of an octavo volume. There are but two medical works in the English language entitled to this distinction, Dr. Young's on Consumptive Diseases and Dr. Cooke's on Nervous Diseases. Each has proceeded from a most distinguished scholar, and each gives in a condensed form an original and authentic abstract of opinions of all preceding authors on the subject of the particular diseases which form the topics of their consideration. If such a scheme as has been carried out by these two learned men could be pursued, how much time might be saved to the student, and how greatly diminished

might be the shelves of our present libraries. But it is vain to indulge the expectation, for there are too few qualified to accomplish such an undertaking."

After the year 1817 Dr. Young largely decreased his activities as a medical practitioner and only one further reference is made to these matters. This was in connection with his interest in the "Proper Value of the Expectation of Life," or, more simply, Life Assurance. In 1816 he published a paper containing an algebraic expression for the values of lives, and gained fame in this branch of mathematics. Eight years later (March, 1824) the Directors of the Palladium Insurance appointed him Inspector of Calculations. He was permitted to hold the appointment of Physician conjointly; i.e. he was medical referee.

Dr. Young's success in subjects other than medical together with his private income allowed him to retire early from actual practice. The extreme range of his investigations, while officially a doctor, is brought out very clearly in a letter of December, 1820, which was written to a friend who was less happy in his leisure:

"About this time last year I was giving myself a holiday of a few weeks, and I fell into a fidgety sort of languor, and fancied I was growing old. It wore off very soon, however; I am convinced there is no remedy so effectual for this and other intellectual diseases as plenty of employment, without over-fatigue and anxiety. This autumn I have been in fact going on with a work which I was then almost frightened at having undertaken, and am already printing the first part of it, being only a translation with a commentary; it will do better without my name than with it. I am also writing over again my article on Languages in the *Quarterly Review*, with many additions, for the next Supplement of the *Encyclopedia Britannica*; and a biographical

Memoir on Lagrange will be almost as long, requiring a list of one hundred different papers on the most abstruse parts of mathematics. I have then the business of the Board of Longitude to manage and some of the Royal Society. The Arctic Expedition is now settled; but we are fitting out our explorer for the Cape with all his books and instruments. Then there is a Committee of Elegant Extracts to consider the tonnage of ships, appointed by the Royal Society, the Admiralty, the Board of Trade, and the Treasury—which will not take long, but I shall have the onus. Then there is my hospital—to speak nothing of my private patients, who are very discreet at this time of the year. Then I must not forget that I must shortly do a little more to the hieroglyphics¹; and after one number more I shall be able to judge if the thing is worth considering or not. I suppose the Review of Belzoni will give the subject some popularity.

“I have not seen the article, but I suppose my friend Barrow will feel less remorse in exposing my infidelity to my professional consort than I have generally done myself. Certainly, if a man that is married to a profession cannot avoid keeping a mistress or two, he ought not to be the first to blazen to the world the liberties he takes.

* * * * *

“I have learned more or less perfectly a tolerable variety of things in this world; but there are two things which I have never yet learned, and I suppose never shall—to get up and to go to bed. It is now past twelve o’clock, but I must write for another hour.”

¹ Dr. Young had been interested in Hieroglyphics since 1814, see Chap. XV.

CHAPTER VIII

SOCIAL ACTIVITIES—CLOSING YEARS

THERE is a danger in following the works and discoveries of any great pioneer so closely that his real character and habits are apt to be overlooked. In the present instance one must appeal to the records of those who met Young in his various occupations and leisure, and occasionally to letters wherein he reveals his ambitions, those activities he thinks worth while and his pleasures and disappointments.

Dr. Young enjoyed to the full the good things in life. He was very fond of dancing and riding, besides those pleasures to be obtained by moving in the best society of his day. He was a good conversationalist, and he could take part as a singer or an accompanist—a more valuable asset in those days than at present under the wider mechanization of this art. He had great belief in his own powers, and though some of his friends were convinced of his inability to become a distinguished musician, he remained obdurate, observing that had he the time he would make as great a success of it as of his other labours. He had few of those eccentricities which are often a sign of genius, and we cannot imagine him following the example of Sir Isaac Newton in retiring from the company of a few select friends he was

entertaining to tackle some problem which absorbed his attention. A decisive factor in the normal temperament he displayed was the happiness of his married life. All those who add to the sum-total of human knowledge meet with opposition, and Young was no exception. Misjudged, incompletely understood, unfairly treated by many of those scientists who had chosen to further the knowledge of those subjects which he had so highly endowed by his genius, it needed a devoted and patient understanding wife to help him weather the storms of criticism and abuse which would have soured most men. Miss Eliza Maxwell became his wife the day following his thirty-first birthday—14th of June, 1804. She came of a cultivated and aristocratic family, a branch of the Maxwells of Calderwood Castle, Lanarkshire, with a home-life similar to that of the old Scottish families we have referred to in Young's tour of Scotland. A woman of sound common-sense, she esteemed and understood her husband and had an intuitive comprehension of his work which gave them common interests. If we add to this the mutual regard and affection they had for each other, we can understand why above all things Young was essentially human.

In appearance Young had very engaging features and was considered to be the most handsome of our great physicians. The only portrait we have of him (see frontispiece) was painted by Sir Thomas Lawrence in 1826, and the photograph we add brings out the essential characteristics of his nature. His fine open countenance expresses a kindly disposition and good will. The excellent depth of the

forehead, its broad proportions, and the wide spacing of the eyes portray his intellectual gifts. The thin nose and the mouth indicate culture and refinement. The chin is of good proportions, suggesting strength and tenacity.

It is natural to expect of such a person as Young that his pursuits would be mainly studious. He had the patience and persistence so necessary in overcoming difficulties, and he considered his gifts not greater than other men, attributing his success to the earnestness and diligence of his methods. He was undoubtedly an indefatigable worker, and found his greatest pleasure in tackling a difficult problem. His range of activities was extremely large, and he always found relaxation in taking up another subject after momentarily tiring of the subject upon which he was then engaged. His studies occupied his best working hours, and when these were finished he preferred nothing better than the conversation and company of accomplished women and the amusements of music and dancing. It must be admitted that his excursions into social activities were not always happy. He occasionally gave offence by the apparent dogmatism and off-hand nature of his replies to strangers, but the wide and deep state of his knowledge gave the impression that they were effortless. The call of the open countryside had little appeal to him, and he could not understand anyone who preferred living anywhere else than London. In his travels we find his interests are archæological or associated with modern mechanical objects; he could appreciate the attractiveness of a beautiful sunset, but a waterfall, mountainous country and

snow-capped mountains left him almost unmoved. This is to be expected when the time was ripe for Wordsworth and the Lakeland poets.

Dr. Young displayed little interest in current political opinions and changes; he esteemed his work as a medical man and his scientific pursuits during his leisure as of more moment. Moreover, he was mindful of the position a medical man should occupy in the public eye, and above all he considered it essential to place his medical studies, discoveries, and writings first.

* * * * *

Dr. Young was never happier than when he was engaged upon the applied side of natural philosophy. Here success lies in the choice of correct assumptions without which the theoretical treatment would be so involved as to be too complex or possibly give a result very wide of the mark. Thus his knowledge of hydraulics enabled him to advance an intricate theory of the tides in *Nicholson's Journal* of 1813, and this he extended in the 1817 Supplement of the *Encyclopedia Britannica*. This is considered to be one of his best original papers. In like manner he thoroughly enjoyed himself in applying the related subject of hydro-dynamics to the motion of the blood in the heart and arteries, in which he investigated the manner in which the pulse would be transmitted through the arteries, the actions of the muscular coats and the disturbances of these motions through inflammations and fevers.

In the first decade of the nineteenth century the problem of finding the acceleration due to gravity of

a freely falling body was examined with great care by Captain Kater, and Young's estimate of the errors in the method proved to be most helpful in the discussion of the results offered. This is the most important part of any research and limits the value of the method adopted. Dr. Young prided himself on his mathematical technique and he successfully applied his powers, as we have seen, to the statistics of Life Assurance. His other writings at this period consisted in contributions to the *Encyclopedia Britannica* on the subjects of Bridges, Carpentry and Chromatics, besides the biographies of nineteen contemporary men of science, which are exceedingly well done.

From 1821 he became so occupied with duties in London that he decided to make his permanent home in the capital. In this year he toured the Continent very extensively and found time to recall his impressions of the activities of the French Institute, which had just accepted Fresnel's discoveries in Diffraction, and he also deals with the delight of travel in Italy and the Savoy Alps. A similar holiday abroad was taken in 1824, when he visited Belgium, where the distressing condition of the artisans appears to be similar to those of the industrial England of his own time. "The poor are wretchedly poor—not, as it seems, from want of civilization, but from the excess of it at the moment, the introduction of machinery having thrown thousands out of employment."

Two years later he was made one of the eight foreign associates of the Academy of Science at Paris, in the place of Volta, and thus achieved one

of the highest honours that could be conferred on a man of science.

The year before his death, in 1829, saw him occupied with a mathematical attempt to find the figure of the earth by observations on two points within sight of each other, and he also finished his *Egyptian Dictionary*. At this time he was on the committee of the Board of Longitude—a position he had held for some years—and his procedure was the cause for much comment and attack from members of the Admiralty. He drew up an elaborate report, but the labour accelerated a complaint which terminated in his death on May 10th. Apparently he died from arterial sclerosis, a disease which must have been due to his incessant labour and assails a subject usually at a much later age than fifty-six. Dr. Young was buried at Farnborough church in Kent, and a profile medallion with an inscription on a slab beneath it was placed as a monument in Westminster Abbey. The inscription reads thus:—

SACRED TO THE MEMORY OF
THOMAS YOUNG, M.D.,

FELLOW AND FOREIGN SECRETARY OF THE ROYAL SOCIETY,
MEMBER OF THE NATIONAL INSTITUTE OF FRANCE,
A MAN ALIKE EMINENT
IN ALMOST EVERY BRANCH OF HUMAN LEARNING.
PATIENT OF UNINTERMITTED LABOUR,
ENDOWED WITH THE FACULTY OF INTUITIVE PERCEPTION;
WHO, BRINGING AN EQUAL MASTERY
TO THE MOST ABSTRUSE INVESTIGATIONS
OF LETTERS AND OF SCIENCE,
FIRST ESTABLISHED THE UNDULATORY THEORY OF LIGHT,
AND FIRST PENETRATED THE OBSCURITY
WHICH HAD VEILED FOR AGES
THE HIEROGLYPHICS OF EGYPT.

ENDEARED TO HIS FRIENDS BY HIS DOMESTIC VIRTUES,
HONoured BY THE WORLD FOR HIS UNRIVALLED
ACQUIREMENTS,
HE DIED IN THE HOPES OF THE RESURRECTION OF THE JUST.

BORN AT MILVERTON, IN SOMERSETSHIRE, JUNE 13TH, 1773.
DIED IN PARK SQUARE, LONDON, MAY 10TH, 1829, IN THE
56TH YEAR OF HIS AGE.

PART II

WRITINGS AND PUBLICATIONS

CHAPTER IX

EARLY PUBLICATIONS

(YEARS 1799-1801)

IN the *Transactions of the Royal Society* of January, 1800, there is a paper entitled "Outlines of Experiments and Inquiries respecting Sound and Light, by Thomas Young, F.R.S." This was communicated to Gray, Secretary of the Society, and was read on January 16th. The paper bears clear indication of the thoroughness which characterizes all Young's investigations and is typical of his general method. Let us consider the first paragraph:

"It has long been my intention to lay before the Royal Society a few observations on the subject of sound; and I have endeavoured to collect as much information, and *to make as many experiments*, connected with this inquiry, as circumstances enabled me to do; but the further I have proceeded, the more widely the prospect of what lay before me has been extended; and, as I find that investigation, in all its magnitude, will occupy the leisure hours of some years, or perhaps of a life, I am determined, in the meantime, lest any unforeseen circumstances should prevent my continuing the pursuit, to submit to the Society some conclusions which

I have already formed from the results of various experiments. Their subjects are, 1. The measurement of the quantity of air discharged through an aperture. 2. The determination of the direction and velocity of a stream of air proceeding from an orifice. 3. Ocular evidence of the nature of sound. 4. The velocity of sound. 5. Sonorous cavities. 6. The degree of divergence of sound. 7. The decay of sound. 8. The harmonic sounds of pipes. 9. The vibrations of different elastic fluids. 10. The analogy between 'Sound' and 'Light.' 11. The coalescence of musical sounds. 12. The frequency of the vibrations contributing a given note. 13. The vibrations of chords. 14. The vibration of rods and plates. 15. The human voice, and 16. The temperament of musical intervals."

This is a very comprehensive work and nowadays would form the subject of three or four volumes. Young's linguistic ability was undoubtedly of real service to him in this compilation, and the careful attention he gave to every known work on the subject contributed in no small measure to its success. Each of the subdivisions of the paper has formed the basis of at least one line of research for later scientists, and for our purpose it will be best to follow up the most important statements and facts in the paper.

The divergence of sound treats with the ability of the phenomenon to bend round the corners of obstacles between the source of the sound and the observer. Newton supposed it to spread equally in all directions after diverging from a small aperture, which Young opposes on the ground that there is a greater effect in the forward direction, otherwise how can one explain the simple speaking trumpet? This

led Young to a careful investigation of the formation of shadows by any phenomenon propagated in waves such as water waves, and sound. To-day the term "diffraction" is introduced to describe the peculiar effects arising from the bending of waves round obstacles, and as the same result is obtained with light, Young deduced that it was propagated in a similar fashion. In the above digest one paragraph deals with "The coalescence of musical sounds." Herein he deals with the "Beating of Musical Notes." This occurs when two notes of very nearly the same pitch or frequency are sounded together. For example, if the middle "C" of the piano and the note "D_b" adjacent to it were sounded together, we should observe 5 beats per second, supposing the note "D_b" were sufficiently out of tune as to vibrate 261 times per second, it being assumed that C corresponded to 256 vibrations per second. The more nearly the sounds approach the longer the beat period; again, if the sounds are of equal intensity the waxing and waning is much clearer. The explanation can be given when it is realized that the phenomenon is a wave motion; sound waves interfere just as two sets of water waves will interfere. The analogy is followed up in the case of light waves in Chapter X. A parallel case to "Beats" in sound is the much-abused term "Heterodyning" in wireless, where a high-frequency broadcast wave far above the audible limit gives an audible "Beat note" with that of the receiving set which is also above the audible limit. It was by an application of these theoretical considerations implied in the subject of interference of wave motion that Young obtained

successful experimental results which proved conclusively that light is a further manifestation of wave motion.

In his "Analogy between Light and Sound" Young states that Isaac Newton's doctrines of the emanation of particles of light, from lucid substances, though almost universally admitted in this country, was, in fact, directly opposed in others. This corpuscular theory was directly opposite to the suggestion of Huygens, the great Dutch physicist and contemporary of Newton, who advanced the wave theory of propagation. The facts at the time were insufficient to justify either hypothesis, and there is much to support Newton's attitude. Young, however, observes that the insuperable difficulty is partial reflection, for a plate of transparent glass causes a percentage of light corpuscles to be reflected from the surface, whilst others are transmitted. He asks, "Why, of the same kind of rays, in every circumstance precisely similar, some should always be reflected, and others transmitted, appears in this system to be wholly inexplicable." The ether was suggested as a medium for propagating light, and it was supposed to be everywhere. He goes on to say:

"That a medium resembling in many properties, that which has been denominated ether, does really exist, is undeniably proved by the phenomena of electricity. The rapid transmission of the electrical shock shows that the electrical medium is possessed of an elasticity as great as is necessary to be supposed for the propagation of light. *Whether the electric ether is to be considered as the same with luminous ether, if such a fluid exists, may perhaps at some future time be discovered by experiments. . . .*"

If the continual asking of questions and the attempts at linking up diverse subjects is the mark of genius, Young must be admitted such. Great men like Faraday, Newton, and Maxwell have the identical manner of thinking. The postulate in the passage just quoted was realized half a century later when the brilliant theoretical labours of Maxwell combined with the practical demonstrations of Hertz in Germany proved conclusively that electricity and light were essentially different manifestations of the same thing. It was from these obscure beginnings that Wireless Telegraphy came into being.

This same paragraph shows a similar foresightedness.

"It may hereafter be considered, how far the excellent experiments of Count Rumford, which tend very greatly to weaken the evidence of the modern doctrine of heat, may be more or less favourable to one or the other system of light and colours."

At that time the commonly accepted notion was that heat was a "caloric" substance whose presence or absence accounted for hot and cold bodies. The assumption of this imponderable fluid solved some of the problems in heat, but it led into real difficulties which caused the ultimate rejection of the same hypothesis. The early work of Rumford, followed by that of Joule and Lord Kelvin fifty years later, established the nature of heat as one of the many manifestations of energy. In the passage referred to we infer that Young was disposed to accept Rumford's ideas, and points to light as being a kind of energy too. This was one of the great scientific

triumphs of the nineteenth century—the complete proof that thermal radiation and light are of the same nature, viz. wave motion.

April, 1800, saw the publication in the *British Magazine* of an important essay on “Cycloidal Curves.” Young’s paper is written to show that the geometry of the cycloid and curves of a similar nature may be solved by the methods used by the ancient Greeks. The cycloid is the path traced out by a point on the circumference of a wheel rolling along a straight line, and admits of a simple treatment by the algebraic method introduced by Descartes. This method was not favoured by Young, who writes:

“The moderns have very frequently neglected the more essential, for frivolous and superficial advantages. To say nothing of the needless encumbrances of new methods of variations, of combinational analyses, and of many other similar innovations, the strong inclination which has been shown, especially on the continent, to prefer the algebraical to the geometrical form of representation, is a sufficient proof that, instead of endeavouring to strengthen and enlighten the reasoning faculties, by accustoming them to such a consecutive train of argument as can be fully conceived by the mind, and represented with all its links by the recollection, they have only been desirous of sparing themselves as much as possible the pains of thought and labour, by a kind of mechanical abridgment, which at best only serves the office of a book of tables in facilitating computations, but which very often fails even of this end, and is, at the same time, the most circuitous and the least intelligible.”

This, of course, is rather prejudiced, for great advances have been made by using the method of Descartes.

Mr. Brougham, a rising Edinburgh politician, then only twenty years of age, had used the algebraical methods for the solution of the cycloid. His efforts are commented upon by Young thus:

“Undoubtedly there are some cases where algebraical symbols are more convenient than geometrical ones: but when we see an author exerting all his ingenuity in order to avoid every idea that has the least tincture of geometry, when he obliges us to toil through immense volumes filled with all manner of literal characters, without a single diagram to diversify the prospect, we may observe with the less surprise, that such an author appears to be confused in his conception of the most elementary doctrines. . . . He may very easily fancy he has made discoveries, when the same facts have been known and forgotten long before he existed. An instance of this has lately occurred to a young gentleman in Edinburgh, a man who certainly promises, in the course of time, to add considerably to our knowledge of the laws of nature.”

Brougham eventually became Lord Chancellor of England, but before attaining this exalted position he edited the *Edinburgh Review*, and during the next few years all Young's discoveries were attacked with a persistence of scathing satire which must have satisfied “the young gentleman in Edinburgh” for the rest of his life.

We shall return to these attacks, their cause, and Young's replies.

CHAPTER X

THE MECHANISM OF THE EYE

THE eye as an optical instrument has been the subject of much experiment and discussion throughout the ages. The action of a lens in forming an image of distant objects was known to the ancients, but little was done until the time of Galileo, who made a simple telescope out of a combination of lenses. By dissection it had been proved that the eye contains a lens which forms the image on the retina, which is the sensitive part of the eye, corresponding to the photographic plate of a camera. The simplest of cameras will only give good results when the objects photographed are at a sufficient distance. In the case of nearer objects, a more elaborate instrument has to be used which by some extension system will enable the photographer to move the lens further from the sensitive plate until the image is again clearly focused. Such a mechanism was shown by Young to be impossible in the eye, and the question arises as to how we can see objects at a variety of distances without undue fatigue. The process is called the accommodation of the eye. It will be remembered that he found evidence for alteration of the shape of the lens by the action of the ciliary muscles in the eye of an ox which had just been slaughtered. He therefore advanced the theory

that the eye could view objects nearer than the distance of distinct vision, usually 10 inches, by these muscles acting circumferentially on the lens and compressing it so that the thickness at the centre was increased. Such a lens has a shorter focal length, and therefore an object nearer than 10 inches will be brought to a focus on the retina. These observations impressed the scientists of his day, and secured his election to a Royal Society Fellowship. Subsequently apparently contrary evidence of greater scientists caused him temporarily to withdraw his assertions, but in a communication of November 27th, 1800, he returned to his problem, and in a masterly manner demolishes his opponents for good. The paper embraces all facts about the eye which had been observed up to that year, and to these Young adds comments and further discoveries of his own. These were due in part to the invention by Dr. Potterfield of an instrument which furnished a method of determining the focal length of the lens of the eye, and the optical constants of the refracting liquids.

The optometer is of interest historically and in capable hands gave accurate results. The principle upon which it is based is indicated in the diagram, where a point source R is placed on the axis of a lens CD , which is covered by a card with two small apertures A and B placed symmetrically about the axis. If a screen is placed on the far side of the lens two images GH and IK are obtained, and for the position EF they coincide (Fig. 1). If we now take two more point sources S and T and place the screen so that a single image r of

R is obtained, then other images *ss*, *tt* will occur (Fig. 2). If we now join the points T, R and S by a line which is now imagined tilted with respect to the axis, then each point on this line will give two images. This will result in two lines being seen which converge in *r*. Exactly the same situation arises when a distant object is viewed through two pin-holes separated by a distance which

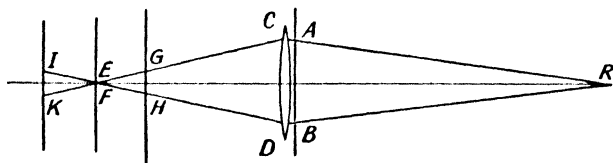


FIG. 1.

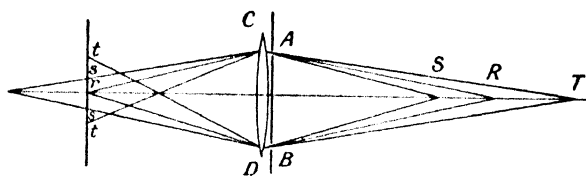


FIG. 2.

is less than the diameter of the pupil of the eye, and if the object is a straight line slightly tilted with respect to the axis of the eye lens the images will cross at the distance of distinct vision. In practice the optometer was made in cardboard or ivory about 8 inches long and 1 inch wide, divided along the length by a fine black line. The latter was viewed through a slider with slits of different sizes from $\frac{1}{10}$ inch to $\frac{1}{10}$ inch in breadth and with spaces somewhat broader, so as to suit pupils of different sizes.

Lenses could be applied to the card for subjects with defective vision. It will be apparent that the instrument will only give concordant results for eyes "at rest."

Using the instrument Dr. Young examined his own eyes, obtaining the focal length of the lens and other quantities, such as the diameter, length of the axis from cornea to retina, and curvature of the cornea. He now made the very important discovery that his eye did not possess equal power in focusing lines at different inclinations to the horizontal, e.g. when he viewed horizontal lines of squared paper the vertical lines were not clearly in focus, and vice versa. This is the first record of astigmatism. He writes:

"My eye in a state of relaxation collects to a focus on the retina those rays which diverge vertically from an object at a distance of 10 inches from the cornea, and the rays which diverge horizontally from an object at 7 inches distance."

He accounts for this defect by the tilt of the lens preventing the latter from being normal to the axis of the eye. He also indicated that spherical mirrors would form astigmatic images.

After a brief indication of how he finds the blind spot and its position, a detailed discussion follows on the processes of accommodation. It had previously been supposed that the eyeball altered in shape and that the cornea altered its bulge or curvature. This Young refuted in a series of excellent experiments. His work has not been improved upon, except in corneal astigmatism which he missed.

The general consensus of opinion is that the most original contribution Dr. Young made in this field was the beginning of the true explanation of colour vision. He had satisfied himself that this was a sensation depending not on the light but on man. The three primary colours were red, green and violet, these being roughly a triple division of the spectrum. Mixtures of these coloured lights will give the other sensations of yellow, mauve and signal green (or peacock-blue), with the other gradations when the colours are not mixed in equal proportions. He cites experiments whereby this mixing may be accomplished, and incidentally gives us the first true explanation of the colour sensations in mixing pigments. Yellow paint shows up in a continuous spectrum of white light only in the yellow and green portions, for it looks black elsewhere, while blue paint shows up in the blue and green. Hence a mixture of these paints has only the green colour scattered when white light falls upon it, the remaining components of the light being absorbed, so that yellow and blue pigments form green.

Helmholtz and Tscherning have greatly advanced Young's theories.

CHAPTER XI

LECTURES ON NATURAL PHILOSOPHY (1807)

THAT a whole chapter is to be devoted to an appreciation of this great work of Young is but scant justice. We shall endeavour to extract such matter which is of general interest, that which makes the author famous, and then analyse it from our modern standpoint.

The work was originally published in two quarto volumes of about eight hundred pages each, and was reprinted in 1845 with additional notes by the Rev. P. Kelland, F.R.S. In this edition one of the volumes is devoted solely to plates, illustrating the matter in the first volume; it also treats less fully his systematic catalogue relating to natural philosophy and the mechanical arts, a compendium which is a most useful source of information for those interested in historical science. The author was to have received £1,000 for the 1807 edition, but owing to the bankruptcy of the publisher he never received it. The wealth of diagrams, mostly drawn by Young himself, make the work good reading, but the language is compressed and in some cases unusually difficult.

The work is divided into three parts, each part containing a score of lectures. The first includes

mechanics, from the theoretical and practical standpoint; the second treats of the equilibrium and motion of fluids, sound and optics; the third deals with elementary astronomy, the tides, gravitation, cohesion, electricity and magnetism, heat and climatology. In the introductory lecture we are given the outline of the plan.

“The phenomena of nature resemble the scattered leaves of Sibylline prophecies; a word only, or a single syllable, is written on each leaf, which, when separately considered, conveys no instruction to the mind; but when, by the labour of patient investigation, every fragment is replaced in its appropriate connection, the whole begins at once to speak a perspicuous and a harmonious language.”

The work of Newton enabled him to connect such diverse phenomena as weight and the motions of the planets by the law of gravitation, and in like manner Faraday's labours indicated how electricity may be generated from magnetism, bringing with the discovery the modern ramifications of electrical engineering. Harvey had explained the principles of mechanics. Young proceeded to examine various types of machines in common use and of historical importance. The section is completed with an account of the arts of writing, engraving, printing, and drawing. He goes on to say:

“All these subjects are in part preparatory to the immediate examination of the mechanical arts and manufactures, which may best be divided into such as are principally employed for resisting, for modifying, or for counteracting any force or motion.”

He follows this by a lecture which deals with the craftsmanship of bricklayers, masons and the joiners, under the title of Architecture and Carpentry.

"The modification of form and motion includes in its communication and alteration, by joints of various kinds, by wheelwork, by cordage, and its equalization by time-keepers. The subject of wheelwork gives considerable scope for mathematical research. . . . The consideration of cordage leads us to that of union by twisting and by intermixture of fibres; including the important arts of carding, combing, spinning, rope-making, weaving, fulling, felting and paper-making."

This paragraph shows the care and penetration he proposes to apply in his lectures. When we come to sound and optics, he writes:

"The doctrine of sound, the theory of music and the construction of musical instruments, are as pleasing to the intellect in theory, as they are gratifying to the senses in practice; but the science of optics is no less interesting, and at the same time far more useful; the instruments which it furnishes are of almost indispensable necessity to the navigator, to the naturalist, to the physiologist, and even to the man of business or *pleasure*. It is perhaps in this science that many persons of the greatest genius have been the most happily employed."

It is interesting to reflect that the cinematograph and sound films are a direct outcome of such pure research. The remaining subjects are similarly dealt with.

We shall now consider in a little greater detail the matter of some of the lectures themselves. In speaking of pressure and equilibrium his illustra-

tions are excellent; as an example we quote the following:

“In the equilibrium of animals we may observe many examples illustrative of the properties of the centre of gravity. When a person stands on one foot and leans forward, in the attitude which is usually exhibited in the statues of Mercury, the other foot is elevated behind, in order to bring back the centre of gravity so as to be vertically over some part of the foot on which he stands. But on account of the convex and somewhat irregular form of the foot, the basis that it affords is really very narrow; hence, when we attempt to stand on one foot, we find it often necessary to use a muscular exertion, in order to bring the point of support to that side towards which we are beginning to fall; and when the basis is still more contracted, the body never remains at rest, but, by a succession of actions of this kind, sometimes too minute to be visible, it is kept in a state of perpetual vibration, without ever attaining such a position as would give it any degree of positive stability, and thus it may be conceived to be supported even on a single point, recovering this position from time to time by means of a slight degree of rotary motion, which is produced by its flexure and by the changes of the position of the extremities: hence, by habit, the arts of rope-dancers and balancers are acquired. Sometimes, however, the position of the balancer is not so difficult as it appears, the curvature of the wire in contact with the foot tending materially to assist him.

“When we attempt to rise from a seat, we generally draw our feet inwards, in order to bring the point of support into, or near, the vertical line passing through the centre of gravity, and to create a tottering equilibrium, which is favourable for the beginning of motion. And before we rise we bend the upper part of the body forwards, in order to preserve a momentum capable of carrying the centre of

gravity beyond the vertical line passing through the point of support."

Further on, in the lecture on "Statics," we get further applications to muscular movement.

"The application of animal force is usually performed by means of a progressive motion. The muscles employed in this process are in general, if not always, the strongest of the body, both by nature and by habit; so that when force alone is required, it is most advantageously obtained from their exertions. In walking, the centre of gravity is moved forwards with a velocity which is nearly uniform. If the legs were perfectly inflexible, the centre of gravity would describe, in succession, portions of circles, of which each leg would alternately be the radius; but if the velocity were great enough to create a centrifugal force more than equivalent to the force of gravity, the pressure would be removed from each leg after the first instant of its touching the ground; the path would become parabolic instead of circular, and the walking would be converted into running: for the difference between walking and running is this, that in running, one foot is removed from the ground before the other touches it; while in walking, the hindmost foot is only raised after the foremost has touched the ground. Now supposing the length of the inflexible leg to be 3 feet, the centrifugal force would become equal to the weight, with the velocity which would be acquired by a heavy body in falling through a foot and a half, that is 10 feet/sec. or 7 miles/hour; and this is the utmost velocity with which it would be mechanically possible to walk with inflexible legs. But the flexibility of the legs makes the progressive motion much more uniform, by softening the angles of the path which the centre of gravity describes, and rendering it either more or less curved at pleasure, so that it becomes mechanically if not physically possible, to walk with a velocity somewhat greater than 7 miles an hour, and to run or dance with as small a

velocity as we please, since we make the path of the centre of gravity somewhat less, or much more curved, than a circle described on the point of the foot as centre."

It is rare to find in works on this subject illustrations so apt and so elegantly written. In the actions which are most apparent and obvious, we find the greatest difficulty in explanation, and it is a distinguishing feature of Young's genius that while paying due deliberation to profound and basic principles, he does not neglect that illustration of fine detail which is necessary for a full understanding of a subject.

We shall next deal with the lecture on "Passive Strength and Friction." Here we find a very thorough treatment of the subject of "Elasticity," both for solids and fluids. The ultimate nature of such properties as extension, compression, flexure, twisting and fracture, must depend on the arrangement of the atoms or molecules of the substance, and this is left by Young to a later chapter; he deals with substances in bulk and the effects observed. Nowadays this particular department of Physics is of the utmost practical importance in all the iron and steel industries, and the various textile and building trades. Problems of the actual thickness and form of girders, fibres, and supporting columns are matters of life and death in the resulting mechanism or structures, and a visit to any modern works will exemplify the theoretical treatment by a variety of apparatus suitable for determining the elastic properties. Young throws out suggestions which we find carried out in these modern machines. For example, the breaking stress of steel is of practical

interest, and is found by an ingenious machine which indicates the stress at the breaking-point, and also the various stages preceding this condition. Young has the following paragraph:

“The simplest way in which a body can be broken is by tearing it asunder. The cohesive force continues to be increased as long as the tenacity of the substance allows the particles to be separated from each other without a permanent alteration of form; when this has been produced, the same force, if its action is continued, is generally capable of causing a total solution of continuity; and sometimes a separation takes place without any previous alteration of this kind that can be observed.”

Recent research has enabled this type of problem to be investigated very thoroughly, in particular X-ray examination indicating the sliding action of the crystal planes in solids.

In a previous paragraph we have stressed Young's ability at illustration, and as a further example we may note his method of introducing the subject of ductility.

“A permanent alteration of form is most perceptible in such substances as are most destitute of rigidity, and approach most to the nature of fluids. It limits the strength of materials, with regard to practical purposes, almost as much as a fracture, since in general the force which is capable of producing this effect, is sufficient with a small addition to increase till fracture takes place. A smaller force than that which has first produced an alteration of form, is seldom capable either of increasing, or removing it, a circumstance which gives such materials as are susceptible of an alteration of this kind, a great advantage for many purposes of convenience and of art. The more capable a body is of a

permanent alteration of form, the more ductile it is said to be; pure gold and silver, lead, annealed iron and copper, wax when warm, glass when red-hot, and clay when moist, possess considerable ductility. Wood admits of little permanent change of form, except in a green state, although it sometimes settles a little when exposed to pressure. Even stone will become permanently bent in the course of years, as we may observe in old marble chimney-pieces. But the most ductile of all substances appears to be a spider's web. Mr. Bennett twisted a thread of this kind many thousand times and shortened it more than a fourth of its length, yet it showed no disposition to untwist."

It is usual in science to name some important quantity or unit with reference to the investigator who was distinguished in the subject to which it refers. As illustrations, such electrical quantities as Amperes, Volts or Ohms are well known, and in connection with the subject of elasticity we have a similar important entity called "Young's Modulus," which is the numerical ratio of the stress to the strain for any material which is stretched in the direction of its length. All this goes to prove that in this subject Young was pre-eminent in his time.

We now turn to the theory of the motion of fluids, or hydro-dynamics, as it is termed technically. Here the most important consideration concerns the phenomena of waves, and it may be safely deduced that Young's knowledge of the subject was materially helpful in his successful research in the kindred subjects of light and acoustics. Later we shall require some of the elementary principles of wave motion in order to appreciate Young's discoveries in optics, and it has been considered appropriate to

give fairly full details of his own treatment. After a brief discourse upon the theoretical determination of the velocity of waves on the surface of water, which had not been done to his satisfaction, he proceeds:

“Whatever corrections these determinations of the velocity of waves may be found to require, the laws of their propagation may still be safely inferred from the investigation. Thus, it may be shown, supposing the waves to flow in a narrow canal of equable length, that, whatever the initial figure of the waves may be, every part of the surface of the fluid will assume in succession the same form, except that the original elevations and depressions, extending their influence in both directions, will produce effects only half as great on each side, and those effects will then be continued until they are destroyed by resistance of various kinds. It may also be inferred that the surface of a fluid thus agitated by any series of impressions, will receive the effects of another series, in the same manner as a horizontal surface, and that the waves, thus crossing each other, will proceed without any interruption, the motions of each particle being always the sum or difference of the motions belonging to the separate series.

“Supposing two equal and similar series of waves to meet each other in such a canal, in opposite directions, the point in which their similar parts meet must be free from all horizontal motion, so that any fixed obstacle in an upright position would have the same effect on the motions of the fluid on either side as the opposition of a similar series; and this effect constitutes the reflection of a series of waves, which is easily observed when they strike against a steep wall or bank; and when this reflection is sufficiently regular, it is easy to show that the combination of the direct with the reflected motions must constitute a vibration of such a nature, that the whole surface is divided into portions which

appear to vibrate upwards and downwards without any progressive motion, while the points which separate the portions remain always in their natural level."

* * * * *

"Many of the phenomena of waves may be very conveniently exhibited, by means of a wide and shallow vessel with a bottom of glass, surrounded by sides inclined to the horizontal, in order to avoid the confusion which would arise from the continual reflections produced by perpendicular surfaces. The waves may be excited by means of an elastic rod or wire, loaded with a weight, by means of which its motions may be made more or less rapid at pleasure; and the form and progress of the waves may be easily observed, by placing a light under the vessel so that their shadows may fall on a white surface, extending in the inclined position above. In this manner the minutest inflections of the surface of the water may be made perfectly conspicuous."

We may add at this point that this is the first occasion on which the "Ripple Tank" is described, and that it forms one of the most delightful methods of demonstrating the laws of optics.

"By means of this apparatus," Young continues, "we may examine the manner in which a wave diverges, when a portion of it has been intercepted, on either side or on both sides. Thus, if a wave is admitted, by an aperture which is very narrow in proportion to its own breadth, into the surface of a part of the water which is at rest, it diverges from the aperture as from a new centre; but when the aperture is considerably wider than the wave, the wave confines its motion in great measure to its original direction, with some small divergence, while it is joined on each side by fainter circular portions, spreading from the angles only."

Here we have the formation of different types of shadow which will furnish critical evidence in the wave theory of light.

“When two equal series of waves, proceeding from centres near each other, begin their motions at the same time, they must so cross each other in some parts of their progress, that the elevations of the one series tend to fill up the depressions of the other, and this effect may be actually observed, by throwing two stones of equal size into a pond at the same instant; for we may easily distinguish in favourable circumstances, the series of points in which this takes place, forming continued curves, in which the water remains smooth, while it is strongly agitated in the intermediate parts. These curves are of the kind denominated hyperbolas, and each point of the curve being so situated with respect to its foci, as to be nearer to one than the other by a certain constant distance.

“The subject of waves is of less immediate importance for any practical application than some other parts of hydraulics; but besides that it is intimately connected with the phenomenon of the tides, it affords an elegant employment for speculative investigation, and furnishes us with a sensible and undeniable evidence of the truth of some facts, which are capable of being applied to the explanation of some of the most interesting phenomena of acoustics and optics.”

The above examples will serve to show Dr. Young's method in subjects which to many students are laborious and mathematically intricate. As a general rule, he excels in his more descriptive parts of a subject, and in judging the various claims of some theories over alternatives. As an illustration of this we may mention his observations on the divisibility of matter. The lecture is entitled, “The Essential Properties of Matter,” and in it we first find

a discussion as to how matter makes itself evident. Next the fact that matter may be divided indefinitely is denied, and we may suppose that Dalton, his contemporary, contributed towards this decision. Speaking of the extent of the divisibility in experience we have the following remarkable paragraph:

“The smallest spherical object, visible to a good eye, is about $1/2000$ inch in diameter; by the assistance of a good microscope we may perhaps distinguish a body one hundredth part as large, or $1/200,000$ inches in diameter. The thickness of gold leaf is less than this, and the gilding of lace still thinner, probably in some cases not above one ten-millionth of an inch; so that $1/2000$ of a grain would cover a square inch, and a portion barely large enough to be visible by a microscope, might weigh only the eighty millionth millionth part of a grain. A grain of musk is said to be divisible into 320 quadrillions of parts, each of which can be smelt. There are even living beings, visible to the microscope, of which a million would not make up the bulk of a common grain of sand.”

One of the best lectures in the book, “On the Measures and the Nature of Heat,” shows Young in his most critical and descriptive mood. It will be remembered that the accepted doctrine of his day was that “Heat” was an imponderable substance for which different substances have different capacities weight for weight, and the hotter the body the more it contained. This hypothesis was only destroyed after much research in the production of heat by mechanical work, chemical and electrical changes, during the first half of the nineteenth century, for which the work of Joule is renowned. We have already indicated that “Radiant Heat” is of the same

nature as "Light," and that Heat is one of the many manifestations of energy. The revolutionary and at the same time correct views of Young written at a time when scientific thought on this particular problem was greatly confused, are expressed as follows:

"If heat is not a substance it must be a quality; and this quality can only be motion. It was Newton's opinion that heat consists in a minute and vibratory motion of the particles of bodies, and that this motion is communicated through an apparent vacuum, by the undulations of an elastic medium, which is also concerned in the phenomenon of light."

If the arguments Young produces in favour of the latter are tenable, then heat must be of a similar nature. He goes on to say:

"It is easy to imagine that such vibrations may be excited in the component parts of bodies, by percussion, by friction, or by the destruction of the equilibrium of cohesion or repulsion."

* * * * *

"If heat when attached to any substance be supposed to consist in minute vibrations, and when propagated from one body to another, to depend on the undulations of a medium largely elastic, its effects must strongly resemble those of sound, since every sounding body in a state of vibration, and the air or any other medium, which transmits sound, conveys its undulations to different parts by its elasticity. And we shall find that the principal phenomena of heat may actually be illustrated by a comparison with those of sound. The excitation of heat and sound are not only similar, but often identical; as in the operations of friction and percussion; they are both communicated by contact and sometimes by radiation; for besides the common radiation of sound through the air, its effects are communicated by contact, when the

end of a tuning fork is placed on the end of a table, or on the sounding board of an instrument, which receives from the fork an impression that is afterwards propagated as a distinct sound. And the effect of radiant heat, in raising the temperature of a body on which it falls, resembles the sympathetic agitation of a string, when the sound of another string, which is in unison with it, is transmitted through the air. The water, which is dashed about by the vibrating extremities of a tuning fork dipped into it, may represent the manner in which the particles at the surface of a liquid are thrown out of reach of the force of cohesion, and converted into vapour; and the extrication of heat, in consequence of condensation, may be compared with the increase of sound produced by lightly touching a long cord which is slowly vibrating, or revolving in such a manner as to emit little or no audible sound; while the diminution of heat, by expansion, and the increase of the capacity for heat of a substance, may be attributed to the greater space afforded to each particle, allowing it to be equally agitated with a less perceptible effect on the neighbouring particles."

The developments in electricity and magnetism have been so rapid that Young's remarks on these subjects are of historical interest only.

It is impossible to conclude our criticism of the lectures without mentioning the "Catalogue" he compiled of references to the material found in his lectures. To-day the research worker can find a great deal about his particular subject by a careful perusal of such a journal as *Science Abstracts*, and, of course, contact with original workers is most helpful. This journal is compiled by a number of scientists whose aim is to give in a small compass suitable for reference, an account of the research being conducted in every country throughout the

world. Dr. Young's task may be judged from the fact that there are some twenty thousand references all sorted into their respective classifications as regards subject, and that the labour involved was equivalent to three years' (1804-07) continuous application. Naturally the English periodicals, such as the *Royal Society Transactions* and the *Journals of the Royal Institution*, receive full reference, but we also find many details of the works of continental philosophers. One interesting sidelight is the evidence it brings of the communications between the French and English philosophers which continued uninterrupted in spite of the French Revolution. Science then as now recognized no barriers.

The arrangement of the "Catalogue" follows the same general line as is found in the Lectures, but Young first gives a summary of the best sources of information on practically every department of mathematics, which is invaluable to the serious student, who must develop a certain mathematical skill and technique before explaining or adding to the theoretical treatment of the various branches of Natural Philosophy. Occasionally in the history of science experiment outstrips theory, and vice versa, but there are always to be found a certain number of mathematicians who apply their knowledge to science. One of the finest contributions in the "Catalogue" is a summary of all that was known on the "Standards and Tables of Measurement." Here is to be found every type of unit in the measurement of length, volume, weight, etc., from the earliest records, and their relation to the modern accepted units. The French were fortunate at this time in

possessing some of the most distinguished mathematicians and scientists the world has known. Lavoisier was probably one of the very few to be executed during the "Terror," for we find Lagrange, Laplace, Legendre, Fourier, Delambre and Lalande recognized by any political faction in turn. Throughout the difficult years of 1792-9 the joint French and English commission continued their work in measuring an arc from Dunkirk to Barcelona, as a basis for the metre, and mainly through the prudence and energy of Delambre was this end attained. Young comments on this work and gives details of the difficult task of comparing the different standards obtaining in the various countries. It is interesting to note that the French were so anxious to throw off the old yoke that the day was divided into ten hours, the hour into a hundred minutes, and the minutes into one hundred seconds—even the months were given different names and the years were measured from the beginning of the Revolution.

We may note in passing the very full references to the strength and elasticity of materials, and as applied in Beams and Floors, Bridges, Roofs and Furniture. In the arts and crafts section, weaving and paper-making are dealt with as carefully as the purely mechanical timekeepers, and anyone desiring information on carriages, drays, harness and saddlery will be satisfied. The subjects of optics and acoustics are also treated in a highly satisfactory manner, Dr. Young occasionally adding his own theories, and estimating the worth of the authorities he cites. As an example, the "Description of Articulate Sounds, with Appropriate Characters," is done in great detail.

As far as the optics is concerned, we need not dwell here on his admirable précis of his published papers, for it is proposed to consider his optical works in a separate chapter. Probably the greatest amount of space is devoted to astronomy, although the subject of heat is treated very fully. In the latter we find suitably classified such diverse subjects as Chauvette's mode of preventing smoky chimneys, Saint-Julien's theories on warm baths, Rumford's new ideas on fireplaces, capacity for heat, and the propagation of heat. There is a particularly interesting reference to an article in the *Décade Philosophique* by Coulomb, whose experiments pointed to all substances being slightly magnetic. Young repeated some of the work and found wherever the effect was noticeable a tendency to small traces of iron as impurity. The whole question was reinvestigated by Faraday, and later on by Curie, the discoverer of radioactivity, with the result that all substances are shown to have slight magnetic properties. A lively record of thunderstorms, ball lightning and other natural electrical phenomena occupies four pages of the "Catalogue," which terminates in a table of Physical Constants, a few notices on Natural History, Botany and Terrestrial Physics.

The reader will conclude from the foregoing remarks that the treatment is somewhat encyclopedic, especially when certain difficulties were hinted in the opening paragraphs. Dr. Young found his contemporaries not very enthusiastic over his work, and in some cases open hostile criticism is to be observed. Writing to his friend, Mr. Gurney, at Cambridge, he states:

"I hear that your townsman, Woodhouse, is now connected with the *Critical Review* and I believe he has exhibited some spleen against me in the last number; he is very angry with me for attempting to clothe the ideas of a short algebraical calculation in the language of words, and professing his inability to understand the paper on cohesion, he thinks it better to attempt to show its obscurity, than to give any extract from the more intelligible parts, or even the heads of the sections. I would rather, however, be severely handled by a man who understands something of the subject, than be treated with affected contempt by a fool, which, by a strange fatality, has hitherto been my lot. My book, however, will certainly be intelligible enough; you have no idea how many well-sounding periods have been condemned, because they contained many hard words."

The reviewer was afterwards one of the foremost mathematical professors at Cambridge and he did compliment Young on his work, though he was not sympathetic to the mathematical treatment of any of the Lectures. When we remember that a century has elapsed before they have been fully understood, we may surmise some of Woodhouse's difficulties, which would not be apparent to Young.

CHAPTER XII

DISCOVERIES IN PHYSICAL OPTICS

THE subject of Light is conveniently divided into geometrical and physical optics. In the first branch the consequences of the laws of reflection and refraction are worked out for narrow beams and cones of light rays incident upon plane and curved surfaces. The treatment is very similar to that followed in the geometry of the ancients, and may be made algebraic by the utilization of Descartes'¹ discovery, so that some schools consider this subject as an interesting branch of mathematics. The domain of physical optics, on the other hand, has limited the range of geometrical optics by the discovery of the true nature of light. Here we are more concerned with what happens to light when it is partly intercepted by an obstacle of some kind, or why a thin film of oil or soap will show such beautiful coloration effects in daylight, and how light is propagated from place to place and with what speed. The best historical account of the developments in physical optics is to be found in Whewell's *History of the Inductive Sciences*, in which the claims of each contributor to our knowledge of the subject are reviewed with great clearness. The culminating point is the epoch of Young and Fresnel, although modern research has

¹ Descartes (1596-1650) discovered that the conic sections could be represented graphically with reference to algebraic co-ordinates.

revealed difficulties in the apparently flawless product of these distinguished researchers. Not that their work has been proved false, but that recent discoveries have required wider and simpler assumptions as to the nature of light than was then deemed necessary. Thus in their optics we find much resemblance to the brilliant discoveries of Newton on universal gravitation, this subject having been extended by Einstein in his theory of relativity. There is, however, this difference, that whereas Newton arrived at the theory of gravitation in a single flight of genius, the corresponding wave theory of light was only established by a number of workers extended over a period of years.

The study of optics as a science prior to Young's day was distinguished by the variety of phenomena investigated experimentally, and the insufficiency of satisfactory explanation based on a simple hypothesis as to the nature of light. Rays of light were thought to travel in straight lines, and the laws of reflection and refraction at plane and curved surfaces had been established experimentally. The velocity of light proved to be exceptionally high, and two schools of thought arose with Huygens, the Dutch philosopher, maintaining that light was a wave disturbance, whilst Newton claimed it to be a corpuscular phenomenon. In the former case we must assume, states Huygens, that the energy sent out from a source of light is in the form of undulations or waves, which, with a point source and uniform surroundings, are spherical. The simple laws, of course, are readily deducible by studying the corresponding hydrodynamic analogy already mentioned, and in the capable hands of

Young many other facts were shown to be a consequence of the wave theory. On the other hand, according to Newton, light consists of weightless particles sent out by a source in much the same way as a machine-gun can shower bullets, or a rain-cloud droplets. It is only fair to state here that Newton conjectured a wave hypothesis, but worked out in mathematical detail the corpuscular theory, giving special properties to the particles when the occasion required, and that his followers were the real defaulters from his ideas by failing to examine with sufficient care the alternative method. Huygens himself used the wave theory to explain double refraction in crystals, but he did not follow the theory to the logical conclusion in the matter of its application in the formation of shadows, as the more distinguished exponents Young and Fresnel did, and in his assumption that light was of the same nature as sound, he missed the real explanation as to why polarization is possible.

We shall now consider briefly the important factors concerned in wave motion, then proceed to the difficulties facing Young, and finally indicate how he applied these factors to the solution of the difficulties. The universal presence of Wireless has resulted in a new scientific vocabulary in which the terms wave and wave-length are very familiar, but when we ask such questions as, "Wave of what kind, of what substance?" or the more fundamental question, "What is a wave?" science must be consulted for exact definition before progress of any sort is possible. In the ripples traversing the smooth surface of water, two distinct characteristics

are noticeable, firstly, the progress of the disturbance with some velocity, the ripples all having the same form, and secondly, the fact that the liquid does not move bodily, for a floating body merely executes a vibration or oscillation in a vertical plane. It is true that in water waves a slight horizontal oscillation is apparent also, but this does not affect our general conclusion that a wave disturbance in water is a propagation of energy by virtue of gravity and any other controlling forces. The wave-length is the distance from crest to crest or from trough to trough, and the scientific term for a wave-front is that it is the surface or line for which the phase of the particles disturbed by the progression of the wave is the same, or, non-technically, the points where the particles are all doing the same thing, i.e. vibrating together up or down. When the vibrations of the particles coincide in direction with the advance of the wave, it is said to be a longitudinal wave, and if at right angles to the direction of propagation, a transverse wave. In the phenomenon of sound the air is alternately compressed and rarefied as the sound impulses traverse the space between the source and receiver, and these minute changes in pressure communicate motion to the tympanum and thence by the mechanism of the ear to the brain. Thus the note middle C generates impulses which are about 53 inches wave-length corresponding to a frequency of vibration of 256 per second. The product of frequency and wave-length gives the velocity of the wave. In the propagation of light the wave theory assumed the necessary medium to pervade everything, even the space between the different heavenly

bodies, so that the changes in elasticity of the ether, as it was called, could account for the wave and its velocity. Thus it was commonly supposed that as the air changed when sound was propagated through it, so the ether was agitated when light passed through it, and that our eyes were therefore sensitive to the vibrations of the ether particles, the retina playing the counterpart of the tympanum in hearing. Another important factor is the range of colours to which the eye is sensitive, and progress in this direction had been made by Newton, who demonstrated the prismatic spectrum and produced a variety of colours in thin films enclosed between a slightly curved and a flat surface. These effects he was able to explain in the first case by the composite nature of white light, for he asserted that each colour had its own refractive index or degree of bending when crossing the interface of two media, and in the second case by giving his corpuscles fits of or preference for easy transmission and reflection, which though it gives a solution in this case is of no use elsewhere.

The difficulties of emission or corpuscular theory were realized by Young, and ably set forth in a paper he read to the Royal Society in January, 1800. Here he stresses the fact that Newton had first suggested the wave theory and in particular had thrown out the hint that colour depends on wave-length. From this he proceeds to attack Newton's chief objection to the wave theory, viz., if light is passed through an aperture, we should get a portion of the light bending round the edges of the aperture, so that, if the light was intercepted by a screen, no

clear image would be received; while in the opposite case small opaque objects should never give sharp shadows when they intercept a beam of light. Young, however, states that the reason why such clear definition is apparent lies in the small wavelength of the light, and in opposition to Newton's claim that sound goes equally round all objects, he insists that high-pitched sounds show the effect in small degree compared to low notes. Thus when a band moves away behind a row of houses, the low notes of the drum are heard after the higher blares of the bugle have died away. Finally, where the undulatory theory triumphs is in its ability to account for partial reflection which accompanies the incidence of light on refracting substances, and its natural result that interference effects should be obtainable as in the hydrodynamic analogue previously mentioned. There is an excellent example of the latter in the tides at Batsha in the East Indies, where twice in each lunar month the tides approach by two channels, whose lengths are half a wave different when they reach the port and the tide disappears. It reappears after seven days, attaining its maximum height of about 12 feet. This observation was first brought to the notice of the Royal Society by Halley, and was successfully explained by Newton's application of the principle of interference.

The first satisfactory application Young makes of his theory is to the colours obtained by the reflection of white light from fine gratings and surfaces of metal in which the polishing process has left a large number of minute scratches. Each line acts as a source sending the light in all directions so as to

reach the eye. If we choose a particular wave, for example, red light, which is related in such a way that the distances from the eye to successive lines, or rulings, increases regularly by half a wave-length of this colour, it will not be perceived by the eye. A slight displacement of the eye will bring it into view, because this may be sufficient to increase the successive distances for the waves of red light to be in step. As an example Young quotes the case of Barton's buttons used for ornament, as they had a similar appearance to that of diamonds. Polished metal plates were stamped by a die of hardened steel which had been ruled with a series of parallel grooves separated by less than one ten-thousandth part of an inch. The same principle is used in the modern reflection grating, which enables the spectroscopist to examine the light of any source and determine readily the wave-length of any component.

Probably the most brilliant interference effects are seen in thin films of oil, soap films and the wings of various insects. Here again Young provided the correct solution, and, moreover, used Newton's own observations of thin films, which he had most ingeniously produced by placing a lens of very small curvature on a flat plate of glass. The thickness of the film varies as we proceed from the point of contact outwards, and it is easy to calculate the thickness at any desired point. In this manner by illuminating the film with white light the following table of colour and thickness was drawn up. For convenience Newton called the repetition of the colours the successive order of the spectra:

TABLE I
TINTS OF NEWTON'S COLOURS OF THIN FILMS

Order.	Film Thickness in millionths of an inch.	Tint in Reflected Light.
1.	0	Black.
	3.5	Gray.
	5.5	Whitish.
	8	Straw.
	10	Orange.
	10.5	Brick red.
	11	Dark purple.
2.	11.5	Violet.
	13	Blue.
	15	Peacock.
	18	Yellow.
	19.5	Orange.
	21	Red.
	22	Violet.
3.	24	Blue.
	25.5	Peacock.
	27	Green.
	29.5	Yellowish green.
	31	Rose.
	32.5	Crimson.
	33	Purple.
4.	34.5	Violet.
	36	Peacock.
	38	Green.
	40	Yellowish green.
	44	Rose.
5.	48	Pale green.
	52	Pale rose.
	55	Rose.
6.	60	Pale peacock.
	64	Pale rose.
	66	Rose.
7.	71	Pale green.
	74	Pale rose.

To account for this change in colour as the thickness increases Young employed his theory of inter-

ference. Consider a film of air between two parallel glass surfaces of thickness t . Then a parallel beam $ABDP$ will be partly refracted and reflected into portions $BCQD$ and $EBDF$ respectively. Confining our attention to the two rays AB and PD in this beam, we note that AB will be split up, part traversing BC and the other BE . In this way a second division occurs at C and again at D . Hence

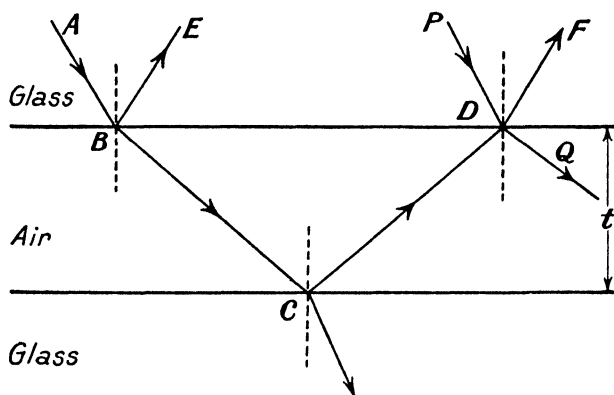


FIG. 3.

a combination of rays is possible when we refer to $ABCDF$ and PDF . Along the direction DF two rays will proceed and interference is possible in this direction if the wave separation BC plus CD is an odd number of half wave-lengths. The diagram becomes yet simpler when AB is perpendicular to the film, and the path difference between the two rays is twice the film thickness. Since the central

spot is black as observed by reflected light, Young was obliged to introduce a half-wave retardation when a ray is partially reflected. This may be at B or at C, for in the first case there is reflection internally in glass at a rarer medium (air), and in the second case reflection at a denser medium—a glass surface. Reading Young's remarks very closely it is apparent that he saw the need for a retardation of half a wave-length at reflection from the analogy of sound. If a condensation of air traverses an organ pipe open at both ends, it will emerge from the open end leaving the air at the end rarefied. This rarefaction proceeds along the tube in the opposite direction to the condensation, and we have therefore a condensation reflected as a rarefaction. This is the same thing as a half-wave retardation. On the other hand, a closed organ pipe reflects the condensation as a condensation by virtue of the fixed end or barrier. Hence two reflections of the same kind for a thin plate should have a bright central spot. This Young ingeniously obtains by interposing oil of sassafras between crown and flint glass plates because the oil has an intermediate optical density or refractive index of the two kinds of glass.

In this case BC is reflected at the optically denser and PD also at an optically denser medium, so that when the film is infinitely thin there is no retardation.

Young gives the argument for the conclusion arrived at above, and it contains references to the principles of impact in dynamics of small with large masses, and vice versa, as well as the acoustic reference already mentioned. He now enters more fully into the theory of the soap film, which he produced

across a wine-glass supported so that the film was vertical—in order that it might drain—and the colours were observed as the thickness diminished. There arise a series of bands of colour which arrange themselves as in the table for Newton's thin films. The diagram illustrates what we should see just before the film breaks. At the upper edge we have

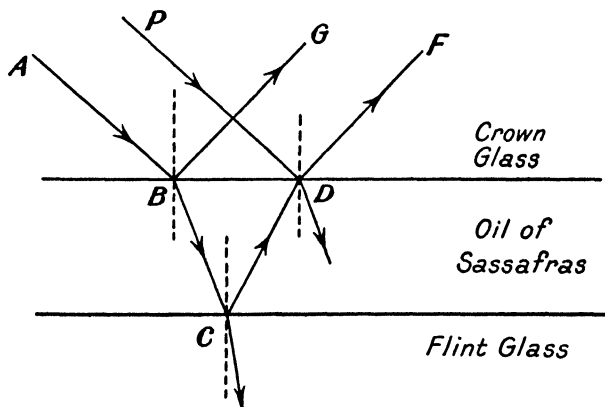


FIG. 4.

a black region surmounting the colours indicated. We therefore conclude the film to be much less than a wave-length thick in this region, and allowing for the half-wave retardation for the two kinds of reflection, the light must interfere and total blackness results as in Newton's experiment. With great care to avoid contamination it is possible to get the whole film black.¹

¹ See appendix.

We shall now proceed to an explanation of why the colours arrange themselves in the order of Table I, and at the same time this will solve the colours produced by soap films. It will be simplest to imagine a film such as Newton used illuminated with light of

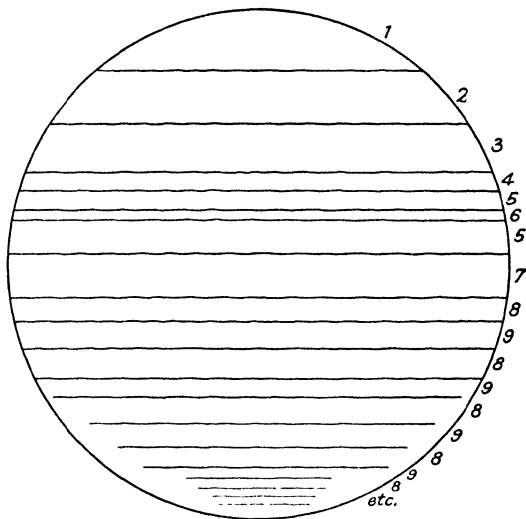


FIG. 5.

1. Black; 2. Gray; 3. Straw; 4. Brownish Red; 5. Purple; 6. Yellow;
7. Greenish Yellow; 8. Green; 9. Pinky Red.

one wave-length only. For example, with yellow light several hundreds of rings are visible, the first appearing where the film thickness is 14 millionths of a centimetre thick, or $5\frac{1}{2}$ millionths of an inch. The next appears at twice this thickness, the third three times the thickness, and so on. The red waves

would give their first bright ring at a point where the film thickness was 17 millionths of a centimetre, or $6\frac{3}{4}$ millionths of an inch. Thus the rings will vary in size according to the light used to illuminate

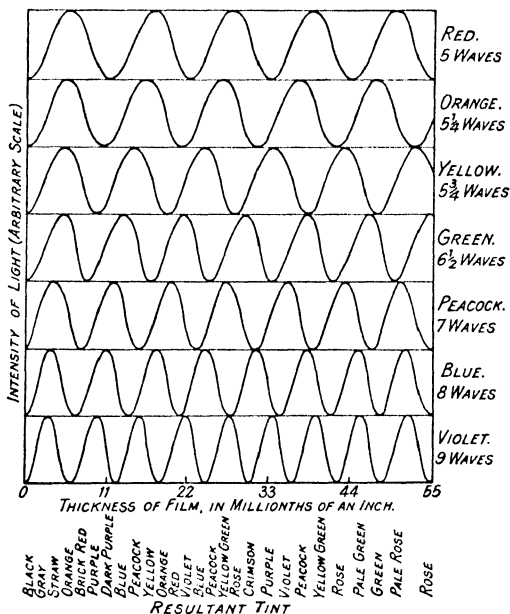


FIG. 6.

the film. Hence the final result of Table I with white light will be obtained by adding up the overlapping colours. This is done diagrammatically above, where the film thickness increases regularly from left to right.

The wave-lengths can be found in various ways, and assuming these are known, they are drawn to scale for the seven colours of the spectrum. The width corresponds to including just over five and a half yellow waves. Hence at any given distance from the centre, the resultant colour will be obtained by adding up the various amounts of coloured light at this point. For example, when the film thickness is $5\frac{1}{2}$ millionths of an inch thick the yellow is a maximum, there is plenty of orange, green and peacock, but little blue and red, and very little violet. Thus the resultant colour will be whitish with a yellowish orange tint. At double this thickness there is a preponderance of blue and violet with a little red, and the other colours contribute very little indeed. This will give a dark purple tint, and ends the first order of the spectra.

Allowing for the half-wave retardation at reflection, we see that since the yellow waves give a bright ring at the point where the thickness is $5\frac{1}{2}$ millionths of an inch, the wave-length of yellow light is about 22 millionths of an inch. Dr. Young draws up a table of colour and wave-length, and the values included agree very well to three-figure accuracy with those we assign to-day (see Table on opposite page).

Young concludes his paper of November 12th, 1801, with a tribute to Hooke, one of the first Royal Society Fellows and a great contemporary of Newton, who in a work termed *Micrographia* suggested that the wave theory would solve the Newton's Rings problem, but as often happens the work was forgotten, and when rediscovered independently by Young, he writes: "It was not till I had satisfied my-

self respecting all these phenomena, that I found in Hooke's *Micrographia* a passage which might have led me earlier to a similar opinion." We must turn, however, to a further paper which Young read before the Royal Society on November 24th, 1803. In the interval he had communicated an "Account of the production of colours not hitherto described,"

Colours.	Length of an Undulation. Millionths of an inch.	No. of Undulations or Cycles per Second.
Extreme . . .	26·6	463 millions of millions.
Red . . .	25·6	482
Intermediate . . .	24·6	501
Orange . . .	24·0	512
Intermediate . . .	23·5	523
Yellow . . .	22·7	542
Intermediate . . .	21·9	561 = 2 ⁴⁸ roughly.
Green . . .	21·1	584
Intermediate . . .	20·3	607
Blue . . .	19·6	629
Intermediate . . .	18·9	652
Indigo . . .	18·5	665
Intermediate . . .	18·1	680
Violet . . .	17·4	707
Extreme . . .	16·7	735
Mean of all or white . . .	22·5	547

but now he feels that he can bring positive evidence before those who may yet doubt the undulatory theory and its application to the problems in hand.

In the ripples on the surface of a sheet of water from two sources it will be found that interference effects should be observed at definite points according to their distances from the sources and the spacing of the sources. Dr. Young obtained like effects

with sunlight by a method which is shown in the diagram.

The light is reflected by a mirror *MM* to reach the hole *H* in the wall *PQ* of the room. *A* and *B* are two small holes in a screen, so providing two sources from the light which spreads from *H* very

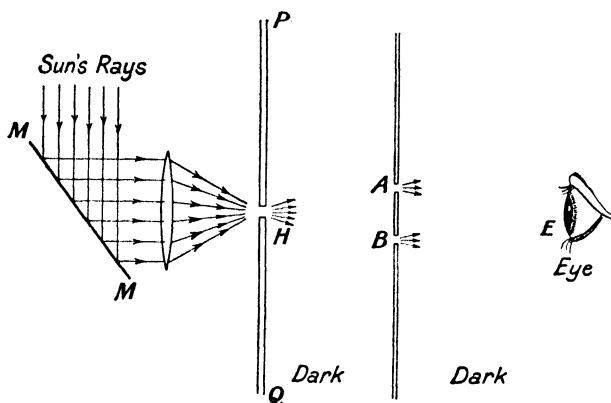


FIG. 7.

slightly. These sources will interfere in the regions where the light spreading from them overlaps. Thus an eye placed at *E* will see interference fringes, their separation being increased as the eye recedes to the right. Young used an alternative method which he describes thus:

"I brought into the sunbeam a slip of card, about one-thirtieth of an inch in breadth, and observed its shadow, either on the wall or on other cards held at different distances. Besides the fringes of colours on each side of the shadow,

the shadow itself was divided by similar parallel fringes of smaller dimensions, differing in number, according to the distance at which the shadow was observed, but leaving the middle of the shadow always white. The result is due to the incident beam being split into two portions by the obstacle, and these are capable of interfering. At the centre of the shadow on the axis they will contribute disturbances which are in step accounting for the white middle of the shadow."

To show that both the beams conspire in these effects, Young covered up one edge of the obstacle and the fringes disappeared. Here again the wavelength of the light may be determined from the spacing of the fringes, the distance from the screen to A, B, and the separation of the latter. The result agreed with the determinations made with thin films.

In the last investigation the edge of the object is never sharp, but is bordered by unequally spaced fringes, which are easily distinguishable from the regularly spaced interference fringes. These new fringes were a problem which Young failed to explain, though he advances a very ingenious explanation on the principles of interference. This phenomenon is termed diffraction and was first recorded by Grimaldi in 1665, and was discovered independently by Hooke about seven years later. Young stated that the fringes were produced by the difference in distance of two rays which arrive at the same point on the screen, one directly and the other by reflection (or infection—a term he introduced) from the edge of the object.

Thus P would be a dark point on the screen if the

difference of $(SA + AP)$ and SP were an odd number of half wave-lengths. O would be the limit of the fringes. The correct solution was offered some fourteen years later in 1817 by Fresnel in France. By investigating more particularly the way in which an undulation propagates itself, he was able to advance upon Huygens' original scheme. Thus Fresnel considered all the parts of a wave of light to

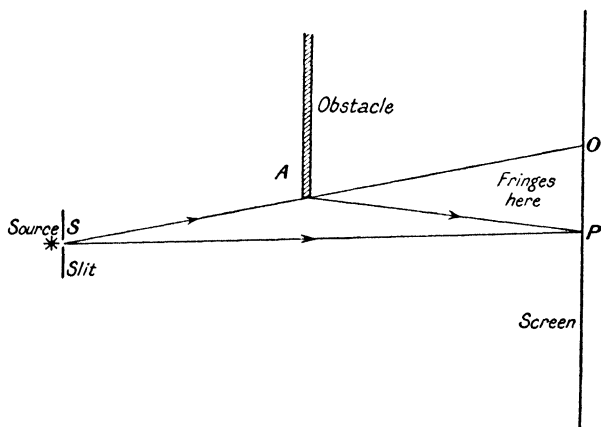


FIG. 8.

interfere with one another, and his ingenious construction and solution will be found in the recognized works on the subject. Fresnel's paper was delivered to the Institute of France on July 29th, 1818, and he was awarded the prize of the Academy of Science in the following year. A preliminary attempt had been made by him in 1815, and through the agency of Arago, it was brought to the notice of the Insti-

tute, but it was not well received. Up to this date Young had been alone in the field, and the entrance of Fresnel with similar ideas discovered quite independently caused the scientific world to recognize the potentialities of the wave theory. Fresnel acknowledged the priority of Young very gracefully when it was pointed out to him by Arago, and both communicated with Young. Arago, writing from Paris, July 13th, 1816, says:

“MONSIEUR,—J’ai l’honneur de vous adresser quelques exemplaires d’un mémoire sur la diffraction de la lumière, que j’ai fait insérer dernièrement dans le nouveau journal que nous rédigeons. M. Gay-Lussac et moi, sous le titre ‘D’Annales de Chimie et de Physique,’ l’auteur, M. Fresnel, ne connaissait pas, quand il l’a composé, les excellens écrits que vous avez publiés, sur cette matière, dans les *Transactions Philosophiques*. Vous verrez que depuis que je lui en ai fait part il s’est empressé de vous rendre justice et de reconnaître l’antériorité de vos titres.”

* * * * *

Further on he refers again to Young’s work in the way it confirms additional experiments of his own, which he hopes to apply to the determination of refractive index. This was realized by Arago, and has become one of the best methods for determining the refractivity of gases.

Later on in the same year Arago visited England and travelled down to Worthing to see Young and discuss the optical discoveries of the period. In spite of the work of Young and Fresnel, the wave theory did not meet with the warm approval and support from the rest of the great scientists of the

day, and Laplace as well as Biot preferred the corpuscular theory. The former had written in 1809 an exposition on Polarization of Light, and as at this stage the wave theory had not been applied with success to this problem, he treated Young's work with scorn, and his word affected the remainder of the Institute, so that Fresnel did not get the recognition he deserved until it was almost too late, for he died at the early age of forty in 1827.

We must now consider the phenomenon of polarization or the "one-sidedness" of light. There are certain crystals, particularly tourmaline, which transmit light, but the light which emerges is peculiar in that a second tourmaline used to transmit it will change the intensity of the light as the crystal is rotated about the axis. In one position the light seems hardly altered by being passed through both crystals, while when the second tourmaline is turned through one right angle, the light is completely cut off. The first tourmaline is called the polarizer, and the second the analyser. There are other methods of polarizing light. Most crystals distinguish themselves by double refraction—a single ray incident is split into two rays when the crystal is suitably placed, and examination with an analyser shows that by setting it to cut out one ray, the other is unaffected, and vice versa. One ray obeys the law of refractions and the other does not, so they were termed ordinary and extraordinary rays. Dr. Young had observed that if a parallel beam of polarized light from a tourmaline was incident upon a plate of crystal and examined with an analyser, then the crystal showed colours depending on its thickness, and moreover a

rotation of 90° in the analyser brought about a change to the complementary colour. For example, if the crystal showed light green, it became a rich mauve. It must be stated that a whole variety of effects, such as rings of colour and even more complicated curves, can be obtained with special beams of light and the crystal set in special manner, but this need not concern us. It is sufficient to state that Young's first idea was that the polarization was due to the vibrations of light being at right angles to the direction of propagation. This was a most unorthodox hypothesis, for it was contrary to dynamical principles; also the elasticity of the ether would be an exceptionally high value, while at the same time with the velocity of light being of such large order, the density would have to be correspondingly small. Laying aside these difficulties, Young next suggested that the ordinary and extraordinary rays vibrated in perpendicular planes, and so that by traversing a crystal with different speeds the two rays would emerge with a path difference depending on the thickness and the difference in the two refractive indices, and on being combined by the analyser would be in a condition to interfere. This advance in the theory was attained with the help of Fresnel, who had shown why it was necessary to use the arrangement of analyser and polarizer and had solved many problems connected with the more complicated effects briefly alluded to above. Again, the two expositors differed in that Young adopted a less satisfactory method than Fresnel, who excelled by his characteristic French genius for mathematical analysis.

The whole problem is therefore very similar to the colours produced on thin films, except that in the present case the separation of the interfering rays is brought about by the difference in velocity of the two rays, while in thin films the interference effect is due to partial reflection and refraction combined with the thickness of the film. Dr. Young quotes an observation made by Professor Chladni, which helped him to get the solution by the difference in speed of the ordinary and extraordinary ray. It is a fact that sound travels one and a quarter times faster along the fibres of a block of Scotch fir than at right angles to them. Thus we see that Dr. Young's intimate knowledge of Sound was of great use in solving the problems in the kindred subject of Light.

In the work of Dr. Young on diffraction, although he was not successful in the theoretical explanation, he made great use of the phenomenon in the construction of an instrument for measuring the sizes of small particles. This he called the "Eriometer," and in its simplest form it consisted of a small circular hole, one-eighth of an inch in diameter, behind which was a source of light of one colour only, i.e. monochromatic. The small particles are placed on a plate of glass and illuminated by the light coming through the aperture. The appearance of the latter changes, for it is surrounded with haloes, of which the diameter depends directly on the size of the particles. Thus by making an experiment with particles of known size, the diameter of any other small particles may be found by simple proportion, after measuring the diameters of the haloes in each case. The experiment is usually made by using

particles of lycopodium, which are very nearly spherical and are remarkably uniform. The arrangement necessary is shown in the diagram.

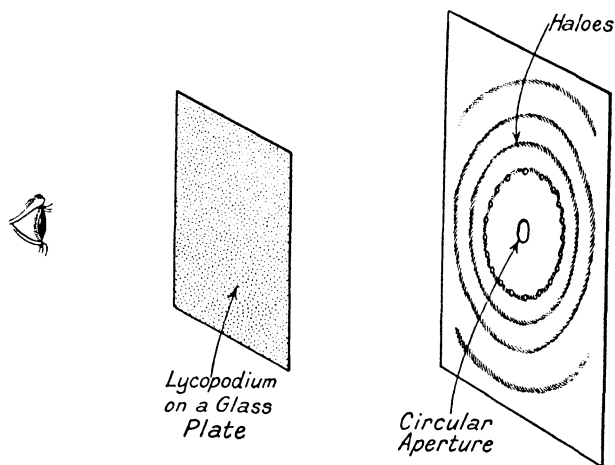


FIG. 9.

The substances he used were blood corpuscles from various animals and the hairs of various animals. For example, in dealing with wool he gives figures for all types, and gives an empirical method of estimating the value per pound. For fibres which can be arranged parallel, he says that a fine slit is preferable to the circular aperture.

The method was used later for finding the size of the small droplets in various types of clouds.

It will be convenient at this stage to mention that Dr. Young used the salts of silver to record the

interference fringes formed by blue light, and the rays to which the eye was insensitive, since called the ultra violet. Into the solutions were dipped paper or leather and the bright rings darkened the sensitive surface. Hence we have the first instance of photography, though in a very incomplete and elementary form.

The reception of Dr. Young's writings on optics and the criticisms are of such interest that the following chapter will be devoted to correspondence which furnishes interesting evidence of the recognition which the scientific world was at last compelled to accord him.

CHAPTER XIII

CONTEMPORARY CRITICISM OF DR. YOUNG'S WORK ON OPTICS

THE beginning of the nineteenth century saw the rise of many cultural periodicals which undertook to place before the public the progress of science and of the humanities. Among these were the *Quarterly* and *Edinburgh Reviews*, the latter being particularly fortunate in its able contributors. Probably one of its most able reviewers was Brougham, the leader of the younger section of Edinburgh society, a man who commanded an effective style with knowledge of a wide and varied character. He had been attacked and corrected by Young in the early work he did in connection with mathematics, and, as we have already mentioned, he was able to return with interest, under a cloak of anonymity, criticism of Young's work on optics. Both Young and Brougham were very able men, but whereas Brougham could influence the general reading public through the medium of his paper, Young could only command the ear of the most accomplished scientists of the day and one or two enlightened ministers of the Government. Hence the majority who preferred to obtain their ideas through the more easily assimilable form of the Review condemned Young as a scientist, and considered his

optical discoveries a travesty of Newton's genius. A specimen of Brougham's handiwork which follows illustrates his style. He discusses Young's lecture on "The Theory of Light and Colours":

"As this paper contains nothing which deserves the name either of experiment or discovery, and as it is in fact destitute of every species of merit, we should have allowed it to pass among the multitude of those articles which must always find admittance into the collections of a Society which is pledged to publish two or three volumes every year. The dignities of the author, and the title of Bakerian Lecture, which is prefixed to these lucubrations, should not have saved them from a place in the ignoble crowd. But we have lately observed in the physical world a most unaccountable predilection for hypothesis daily gaining ground, and we are mortified to see the Royal Society, forgetful of those improvements in science to which it owes its origin and neglecting the precepts of its most illustrious members, is now, by the publication of such papers, giving the countenance of its highest authority to dangerous relaxations in the principles of physical logic. We wish to raise our feeble voice against innovations that can have no other effect than to check the progress of Science, and renew all those wild phantoms of the imagination which Bacon and Newton put to flight from her temple. We wish to recall philosophers to the strict and severe methods of investigation pointed out by the transcendent talents of those illustrious men, and consecrated by their astonishing success."

In connection with Dr. Young's hypothesis of interference, the Review adds:

"A hypothesis which is assumed from a fanciful analogy or adopted from its apparent capacity of explaining certain appearances, must always be varied as new facts occur, and must be kept alive by the same process of touching and

retouching, of successive accommodation and adaptation, to which it originally owed its puny and contemptible existence. But the making of a hypothesis is not the discovery of a truth. It is a mere sporting with the subject; it is a sham-fight which may amuse in the moment of idleness and relaxation, but will neither gain victories over prejudice and error nor extend the empire of science. It is the unmanly and unfruitful pleasure of a boyish and prurient imagination, or the gratification of a corrupted and depraved appetite. If, however, we condescend to amuse ourselves in this manner we have a right to demand that the entertainment be of the right sort, and that the hypothesis be so consistent with itself, and so applicable to the facts, as not to require perpetual mending and patching; that the child we stoop to play with shall be tolerably healthy, and not of the puny sickly nature of Dr. Young's productions, which have scarcely stamina to subsist until the fruitful parent has furnished us with a new litter, to make way for which he knocks on the head, or more barbarously exposes the first."

The 1802 paper of Dr. Young calls forth a further rebuke from the Reviewer and an admonition to the Council of the Royal Society to prevent a degradation of their Institution, which has so long held first rank among scientific bodies, by no longer accepting any publications by Dr. Young on the subject of Interference.

In the ninth number of the *Edinburgh Review* the attack is again renewed with fresh vigour and even greater sarcasm. After advancing his own explanations of the experiments mentioned in Dr. Young's paper, he still feels that the subject has not been pursued with the care and diligence of Newton, and goes as far as to put forward the opinion that the removal of the interference fringes

in the shadows of a fine wire or hair by covering up one side of the hair was inaccurately made. He then adds:

"We may now dismiss for the present the feeble lucubrations of this author, in which we have searched without success for some traces of learning, acuteness and ingenuity, that might compensate his evident deficiency in the powers of solid thinking, calm and patient investigation, and successful development of the laws of Nature by steady and modest observation of her operations."

The attitude of the Reviewer to the Royal Institution and its adherents is made clear in the comprehensive diatribe, for early on in this organized attack he writes:

"Has the Royal Society degraded its publications into bulletins of fashionable theories for the ladies of the Royal Institution? *Proh pudor!* Let the Professor (Thomas Young) continue to amuse his audience with an endless variety of such harmless trifles, but in the name of science, let them not find admittance into the venerable repository which contains the names of Newton, and Boyle, and Cavendish, and Maskelyne, and Herschel."

Dr. Young's answer to such criticism was the publication, in the form of a pamphlet, entitled *A Reply to the Animadversions of the Edinburgh Reviewers*. It is a classic utterance showing the true character of Young, his sense of values, his aim as a philosopher, the nature of his approach to his epoch-making discoveries, and the spite of his unjust critic. His opening paragraph runs:

"A man who has a proper regard for the dignity of his own character, although his insensibility may sometimes be awakened by the unjust attacks of interested malevolence,

will esteem it in general more advisable to bear, in silence, the temporary effects of a short-lived injury, than to suffer his own pursuits to be interrupted, in making an effort to repel the invective and to punish the aggressor. But it is possible that art and malice may be so insidiously combined, as to give the grossest misrepresentations of semblance of justice and candour; and, especially where the subject of the discussion is of a nature little adapted to the comprehension of the generality of his readers, even a man's friends may be so far misled by a garbled extract from his own works and by the specious mixture of partial truth with essential falsehood, that they may not only be unable to defend from the unfavourable opinion of others, but may be disposed to suspect, in spite of their partiality, that he has been hasty and inconsidered at least, if not radically weak and mistaken. In such case, he owes to his friends such explanations as will enable them to see clearly the injustice of the accusation, and the iniquity of its author; and, if he is in a situation which requires that he should in certain degree possess the public confidence, he owes to himself and to the public to prove that the charges of *imbecility of mind* and perversity of disposition are not more founded with regard to him, than with regard to all who are partakers with him in the avoidable imperfections of human nature.

"Precisely such is my situation. I have at various times communicated to the Royal Society, in a very abridged form, the results of my experiments and investigations relating to the different branches of natural philosophy: and the Council of the Society, with a view perhaps of encouraging patient diligence, has honoured my essays with a place in their *Transactions*. Several of these essays have been singled out, in an unprecedented manner, from the volumes in which they were printed, and have been made the subjects in the second and the ninth numbers of the *Edinburgh Review*, not of criticism, but of *ridicule and invective*; of an attack, not only upon my writings and my literary pursuits, but

almost on my moral character. The peculiarity of the style and the tendency of this attack has led me at once to suspect, *that it must have been suggested by some other motive than the love of truth*; and I have both internal and external evidence for believing, that the articles in question are, either wholly, or in a great measure, the productions of an individual, upon whose mathematical works I had thought it necessary to make some remarks, which though not favourable, were far from being severe; and whose optical speculations, partly confuted before, and already forgotten, appeared to their fond parent to be in danger of a still more complete rejection from the establishment of my opinions. As far as my reputation in natural philosophy is concerned, I shall consider a libel of this kind as neither requiring nor deserving an answer; but I cannot help feeling the propriety of endeavouring to defend myself from the more pernicious influences of those imputations, which might tend to lessen the confidence of the public in the professional qualifications of a man whose abilities have been thus contemptuously and repeatedly depreciated. The practice of physic has always been, either immediately or remotely, the object of my pursuits, and I can affirm, without fear of contradiction, that I have never neglected any opportunity either of improving myself in its study, or of being useful to the humblest of those who have committed themselves to my care, in its application. But I have no right to expect that any degree of industry that I may have employed, should encourage a man to entrust me with the management of that which so nearly concerns his happiness and prosperity, if he has reason to think me rash and wavering in my opinions, and that even upon subjects which are generally supposed to admit of proofs perfectly decisive and satisfactory."

Next he answers the insolent admonition of the Reviewer that he had never studied "the plainer parts" of the works of Newton, and in the lecture

on Light and Colours altered his opinions, imputing to him a "vibratory and undulatory" mode of reasoning. The Reviewer had unnecessarily referred to the earlier communication in 1793 on "The Eye and Vision" of Young, and his change in attitude up to the more complete paper of 1800, when he returned to his original theory after a more exact period of experimental inquiry. To vindicate himself Young goes on to show why he actually read the works of Newton. He accounts, too, for his excursions into the extensive regions of natural philosophy, though primarily a medical man.

"It is now fourteen years since I first resolved to devote my life to the profession of physic. I continued for two years the pursuit of those attainments, in mathematics and general literature, which had before constituted my sole occupation; and which by the express sentiment of the father of the medical sciences, and by the universal suffrages of the more liberal part of mankind, have been allowed to be the surest and best foundation for the superstructure of the requisite qualifications of a physician. The causes of disease, obscure in their nature, and hidden in their operation, elude but too frequently the most diligent researches of the strongest and most experienced minds: they afford ample scope to the most minute investigation, and the most sagacious discernment; but they require that the faculties of the observer should have been sufficiently prepared, by being employed on subjects of a nature more certainly definable, and more perfectly intelligible. Classical literature, mathematical philosophy, chemistry and natural history, a knowledge of different countries, and an acquaintance with different languages, are as necessary to the melioration of those powers of reasoning which are to be called into activity in the pursuit of a profession, as they are essential

to the perfection of the character of a general scholar, and an accomplished man. This must be my excuse for having devoted a considerable portion of my attention to the study of the classics, on my success in which the Edinburgh Reviewers have, with an insulting affectation of candour, thought fit on another occasion to compliment me. I pursued the study of mathematics and natural philosophy as far only as I esteemed them subservient to other objects, not that I preferred philology to science, but because I thought myself obliged to sacrifice both to Physic. After having rendered myself familiar with many other mathematical works, I read in the autumn of 1790 both the *Principia* of Newton and his *Optics*. I read not the 'plainest parts of the *Principia*' only, but the whole; and all that illustrious author meant to be understood by a reader, I understood and admired: where he purposely omitted a demonstration, I did not at that time attempt to investigate it. That I was then satisfied with some few parts, which I do not now think unexceptionable, might easily have happened, even if I had felt less reverence than I have uniformly done for the character of the unrivalled author. The *Optics*, too, I read with attention and delight, yet by no means with the same satisfaction that I had derived from the perusal of the *Principia*."

Dr. Young now indicates how his attention to optical subjects was revived, when he considered the problem of vision; and how his success in this field was appreciated everywhere. In particular Dr. Olbers, who advanced contrary theories, on reading the celebrated paper of 1800 acknowledged that it completely refuted his own theory respecting the changes of the eye, and in a letter to Young states that he was glad of this advance in science, since their object was to discover truth and not support to their opinions—the fault of the Edin-

burgh Reviewer. He continues with an outline of how he came to be interested in theories of light.

“When I took a degree in physic at Göttingen it was necessary, besides publishing a medical dissertation, to deliver a lecture upon some subject connected with medical studies: and I chose for this, the formation of the human voice. A few pages, containing a table of articulate sounds, were printed at the end of my dissertation, *On the Preservative Powers of the Animal Economy*: my uncle, Dr. Brocklesby, at the instance of the late most respectable Dr. Heberden, repeatedly urged me to give some further explanation of the subject to which these characters related. When I began the outline of an essay on the human voice, I found myself at a loss for a perfect conception of what sound was, and during the three years that I passed at Emmanuel College, Cambridge, I collected all the information relating to it that I could procure from books, and I made a variety of original experiments on sounds of all kinds, and on the motions of fluids in general. In the course of these inquiries, I learned to my surprise, how much further our neighbours on the continent were advanced in the investigation of the motions of sounding bodies and of elastic fluids, than any of our countrymen; and in making some experiments on the production of sounds I was so forcibly impressed with the resemblance of the phenomena that I saw, to those of the colours of thin plates, with which I was already acquainted, that I began to suspect the existence of a closer analogy between them than I could before have easily believed. On further reflection and examination my opinion was confirmed, and as I thought I could place the question in a clearer light than that in which it had generally been viewed, I was induced to insert my observations in a paper, which I presented soon after to the Royal Society, under the name of ‘*Outlines of Experiments and Inquiries respecting Sound and Light.*’ A determination to confine my studies as

much as possible to physic was my motive for laying them before the Society in a state of confessed imperfection. . . .”

The opinion expressed by the Reviewer that Young was the sole champion of the undulatory theory of light is next refuted by a volume of evidence wherein Young shows that Newton himself was undecided as to which theory would prove the more fruitful, and such distinguished philosophers as Euler, D'Alembert, Lalande and even Laplace were dissatisfied with certain statements in Newton's *Optics*, though they had no experimental evidence to hand to decide for or against. Young adds:

“I have been accused of insinuating ‘that Sir Isaac Newton was but a sorry philosopher.’ But it is impossible that an impartial person should read my essays on the subject of light without being sensible that I have as high a respect for his unparalleled talents and acquirements as the blindest of his followers, and the most parasitical of his defenders. I have acknowledged that ‘his discovery of the composition of white light would alone have immortalized his name’; that the very arguments which tend to overthrow his hypothesis respecting the emanation of light, ‘give the strongest proofs of the admirable accuracy of his experiments’; and that a person may, ‘with the greatest justice, be attached to every doctrine which is stamped with the Newtonian approbation.’ The printer of the Review, feeling perhaps the last expressions would militate too much in my favour, has thought fit to plunder me of them, by omitting the marks of quotation, and attributes them to my antagonist. But, much as I venerate the name of Newton, I am not therefore obliged to believe that he was infallible. I see, not with exultation, but with regret, that he was liable to err, and that his authority has, perhaps, sometimes even retarded the progress of science. The mistakes have been acknow-

ledged and corrected by later writers: other persons, less considerate, have attacked him where he was least invulnerable. One of these is the gentleman whom I have reason to think the author of the remarks to which I am replying, and who, having first accused Newton of a palpable and fundamental blunder, appears now to be desirous of securing to himself the exclusive privilege of questioning his authority. What I have hitherto said relates to the state of the question respecting the nature of light, as it stood before the publication of the first of the papers which have excited so much virulence. But I assert that this paper contains an argument, sufficient to convert that which before was doubt and conjecture, into probability and conviction. It was in May, 1801, that I discovered, by reflecting on the beautiful experiments of Newton, a law which appears to me to account for a greater variety of interesting phenomena than any other optical principle that has yet been made known."

Young now describes the phenomenon of interference in water waves, and points to the analogy in sound and light, and then he says:

"It is unnecessary, on this occasion, to enter minutely into the consequences of the law of interference of light: they have been the principal subjects of the three papers which have drawn down upon me the repeated anathemas of the self-erected Inquisition of the North. Not a single argument has been produced to invalidate it.

"In order to answer the charge of inconsistency in my opinions respecting the nature of light, I must begin by observing that there are two general methods of communicating knowledge; the one analytical, where we proceed from the examination of effects to the investigation of causes; the other synthetical, where we first lay down the causes, and deduce from them the particular effects. In the synthetical manner of explaining a new theory we necessarily begin by assuming principles, which ought in such a case,

to bear the modest name of hypotheses; and when we have compared their consequences with all the phenomena, and have shown that the agreement is perfect, we may justly change the temporary term *hypothesis* into theory. This mode of reasoning is sufficient to attach a value and importance to our theory, but it is not fully decisive with respect to its exclusive truth, since it has not been proved that no other hypothesis will agree with the facts.

"It is exactly in this manner that I have endeavoured to proceed my researches. By analysing the experiments of Newton and comparing them with my own, I had arrived at principles, to which I gave in my paper on the theory of light, the unassuming title of hypotheses; after comparing these principles with all the phenomena of light, and showing their perfect consistency, I thought myself authorized to make a conclusion, in my ninth proposition, which converts the hypothesis into a theory. I was justified in doing this because no man had ever attempted to advance a theory which would bear to be compared mathematically with the phenomena that I enumerated."

The touchings up which Young found necessary in the elaboration of his theory are now dealt with, and a correction is also given in accordance with a discovery made at that time by Wollaston. We now come to the diatribe on theory and hypothesis in which it was asserted by the Reviewer that "a hypothesis is a work of fancy useless to science." Young first indicates that this conclusion could only follow from "such hypotheses as have neither been deduced from experiments, nor afterwards compared with them." Again, the insinuation that theory is harmful and the work of infancy or dotage is contradicted by Young's examples of useful theories in divers subjects, and he continues:

"The speculations which I have extracted from Newton's writings he is determined to show were merely the amusements of some vacant hours at the close of his scientific career. It is very true that the *queries* of Newton were given to the world at a time when his brilliant and solid discoveries were fully established; but the papers which explain all his hypotheses concerning light the most at large, and to which I have had the most frequent occasion to refer, were read to the *Royal Society* more than ten years before he began to write his *Principia*; and the principal reason that delayed their publication appears to have been apprehension of disputes with Dr. Hooke. Some were published in the *Optics* shortly after Dr. Hooke's death; others are only to be found in Birch's history of the Royal Society. Had I not taken care to annex the dates to my quotations, the Reviewer might easily have pleaded his ignorance in excuse for his misrepresentations.

* * * * *

"In the first paragraph of the review of my paper on the production of colours, the writer confesses that he has not 'sufficient fancy to discover' how the 'interference of two portions of light' could ever produce an appearance of colour. The poverty of his fancy may easily be admitted, but it is unfortunate that he either has not patience enough to read, or intellect enough to understand, the very papers that he is criticizing; for, if he had perused with common attention my Bakerian lecture on light, he might have understood such a production of colour without any fancy at all. He then quotes from me the assertion, that a 'black hair' does not produce the appearance of interference fringes, and he has even modesty to refer to a certain page of my paper. I have there said, that a 'horse hair' did not produce that appearance; and I have left it for the Reviewer to decide whether the *horse* should be white or black. The truth is, that a fine wire or a small hair, whether black or white, exhibits equally well the colours I have described. If the

fact were otherwise, it would be equally unintelligible; for there is absolutely no foundation for the Reviewer's insinuation that any theory of these colours was deduced by De Dominis, or can be deduced by any other person, from the laws of refraction. He asserts that it is mathematically impossible for the light to bend round a hair; Grimaldi has long ago experimentally demonstrated this flexion, and called it diffraction; an effect which furnishes the most striking analogy between the motions of light and those of the waves of water."

In answer to a query about the change of half a wave at reflection of the surface of separation of two media of different optical densities, which Young brilliantly proved with and without oil of sassafras in the space between a lens of crown glass resting on a plate of flint glass, the Reviewer again refers to Newton, whom he misquotes, and so leaves the field again in triumph to Young. He follows up with the following statement:

"I have discovered the different flexibility of light is *admitted*, in the absurd and unwarranted sense it is here employed, *by three writers only*. The first is Mr. Henry Brougham, the second the anonymous author of an article in the *Encyclopædia Britannica*, and the third the assailant whose injurious attacks I am now repelling. From so remarkable a coincidence, I think myself authorized to conclude that these three writers are one and the same.

"I have now answered everything that was intended as an argument, in the articles published in the second number of the Review. This constitutes, in fact, but a small part of those articles: they have much less the appearance of impartial discussion of a long-disputed question in natural philosophy, than of the buffoonery of a theatrical entertainment, or of the jests of a peer advocate, endeavouring to

place in a ridiculous light the evidence of his adversary. To answer such an attack in similar language would be degrading; to attempt to oppose it by argument would be futile. I shall refrain, therefore, from noticing any of the additional scurrilities which have been copiously intermixed by the same writer with his remarks on my last paper. I say the same, because I am unwilling to suppose that this island has produced two persons capable of so stupidly misunderstanding, and so wilfully misrepresenting."

The most unpardonable criticism that Brougham advanced was the statement that Young had not performed the experiment of covering up one side of the hair producing interference fringes sufficiently carefully. Naturally this experiment is the most direct proof of the law of interference, and has been performed countless times since. Young therefore adds:

"The Reviewer has afforded me, in the next observation, an opportunity for a triumph as gratifying as any triumph can be where the enemy is so contemptible. Conscious of inability to explain the experiment which I have advanced, too ungenerous to confess the inability, and too idle to repeat the experiment, he is compelled to advance the supposition that it is incorrect, and to insinuate that my hand may easily have erred through a space so narrow as one-thirtieth of an inch. But the truth is, that my hand was not concerned: the screen was placed on a table and moved with the utmost caution; the experiment succeeded where the breadth of the object was doubled or tripled; and I assert that it was as easy to me to estimate an interval of one-thirtieth of an inch, as an interval a hundred or a thousand times as great. Let him make the experiment and then deny the results if he can."

Further contentions of the Reviewer are as sum-

marily dealt with, and Dr. Young concludes with an answer to the vulgar references to the Royal Institution.

“The Reviewer has thought proper to unite in several instances, with his invective against me, some ridicule of the objects of the Royal Institution of Great Britain; an institution in which its Managers have studied to concentrate all that is useful in science, or elegant in literature. This connection appears to him to add so much weight to his arguments, that he has chosen without further provocation, to insinuate its existence more than a year after it had been dissolved. I accepted the appointment as Professor of Natural Philosophy of the Royal Institution as an occupation which would fill up agreeably and advantageously such leisure hours as a young practitioner of physic must expect to be left free from professional cares. I was led to hope that I should be able to impress an audience formed of the most respectable inhabitants of the metropolis, with such a partiality as the moderately well informed are inclined to entertain for those who appear to know even a little more than themselves of matters of science; that I might be of use to the public in disseminating the true principles of natural philosophy; and that I might in future be remunerated by the enjoyment of a more extensive confidence in my professional abilities than could have been granted to a person less generally known. While I held the situation, I wished to make my lectures as intelligible as the nature of the subjects permitted; but I must confess that it was not my ambition to render them a substitute for those of any superficial experimenter that was in the habit of delivering courses of natural philosophy for the amusement of boarding schools. Whatever may have been the imperfections of my lectures, it cannot be asserted, except perhaps in the *Edinburgh Review*, that they were fit for audiences of ladies of fashion only. After fulfilling, for two years, the duties

of the Professorship, I found them so incompatible with the pursuits of a practical physician, that, in compliance with the advice of my friends, I gave notice of my wish to resign the office. I think it, however, just to the Institution, to the public and to myself, that the result of my labours, throughout the whole extent of natural philosophy and the mechanical arts, should be rendered of some permanent utility, and I have since collected such a mass of further reference to works of all ages and of all nations, accompanied by many notes and extracts from them, that it will henceforward be easy for every student and every author to know at once what has been done, and what remains to be done, in the subject of his particular researches, and to what books he must apply for the best information, when further information is required, and can be obtained. Considering how widely this information is at present scattered, I trust that I shall have rendered a service of some importance to every department of the science, and I am now on the point of preparing my book for immediate publication. With this work my pursuit of general science will terminate: henceforward I have resolved to confine my studies and my pen to medical subjects only. For the talents which God has not given me, I am not responsible, but those which I possess, I have hitherto cultivated and employed as diligently as my opportunities have allowed me to do; and I shall continue to apply them with assiduity, and in tranquillity, to that profession which has constantly been the ultimate object of all my labours."

This reply was published towards the end of the year 1804, and Young asserts that he published it in the form of a pamphlet. Only one copy was actually sold and the general consensus of opinion remained hostile to his merits as a man of science and to this particular theory. It was left to the continental research workers to rediscover the principle.

CHAPTER XIV

CAPILLARITY—YOUNG A MODERN PHYSICIST

THE surfaces of liquids have a remarkable property, of which there are many illustrations of everyday occurrence. A liquid is usually said to find its own level, the surface being horizontal, but we have only to examine a tumbler of water or a dish of mercury to find that this statement is untrue, for at the boundary of the liquid where it closely approaches the containing vessel, whilst mercury recedes from the boundary, water is found to pile up towards the glass. This accounts for the form of the meniscus of a liquid and is shown to the best advantage in tubes of half an inch diameter. Again, the rapid ascent of liquid through the interstices of a lump of sugar or the corresponding action of blotting-paper and the manner of drying oneself with a towel, are manifestations of a surface force in the liquid. Such an agency must be present for soap bubbles or bubbles of air below the surface of water to be possible. Here we have the liquid acting in precisely the same way as the envelope of an inflated india-rubber balloon, with this difference, however, that experiment shows us the greater the extension of the rubber the greater is the force tending to disrupt it, whereas the surface force of liquids is

the same for almost all possible sizes of bubbles. The magnitude of these forces is considerable, as may be seen by the impossibility of an insect such as the common house-fly to use its wings when once they are thoroughly wetted, and in the extensive forces required to separate two plane surfaces separated by a drop of water. Since one of the simplest methods of demonstrating the phenomenon is by plunging a fine tube or capilla partly into a liquid, so that the height to which it rises above its ordinary level indicates the force in the meniscus opposing the tendency of the liquid to find its own level, this property is termed capillarity. Thomas Young ably summarized the extent of knowledge of the subject, when he approached it in the Lectures (1804), but he added considerably to a better understanding of the phenomenon in a paper published in the *Philosophical Transactions of the Royal Society*, 1805, and again in an article on "Cohesion" for the *Encyclopedia Britannica* of that period. Dr. Young's method suffered in his manner of approach, for his mathematical treatment, though strictly correct and very elegant in its way, failed to attract his contemporaries, who would not trouble to give that attention so necessary to follow the argument in its original form. The publication of a paper on the identical subject by Laplace in the following year turned such attention as Young did receive to the new-comer. It is fairly safe to maintain that Dr. Young's methods were beyond the comprehension of his readers, and we are indebted to the late Lord Rayleigh, who has presented a very clear account of the work of both Young and Laplace,

and with his great insight Rayleigh has made plain the sections of Young's work which had confounded previous readers. The result has been to give Young the credit and honour of being the first to measure the size of atoms, an occupation which has been very successful in a variety of methods in modern research. The Greeks attempted to explain matter and its properties by assuming it to consist of minute particles or atoms, but it was John Dalton, the Manchester chemist, who demonstrated that matter is composed of ultimate units called atoms or combinations of these by appealing to the laws of chemical combination. He was supported in his ideas by Avogadro, who extended the theory and put it in the form which is accepted to-day. It is not our object to follow the rise of the molecular theory and its ramifications in the light of nineteenth-century and modern research, for there are many excellent books on this subject suitable for the scientific and lay reader. We shall, therefore, content ourselves by illustrating in a descriptive, non-mathematical manner the brilliant research of Young on this problem of the size of molecules.

The method of approach is from a different angle, for he endows the particles composing the liquid with properties of attraction which act through a small distance. This he found necessary to account for cohesion in liquids and solids, and it indicates why we have spherical droplets of liquids, if we neglect gravity, for the pull of the particles upon each other will cause the area of the surface to be as small as possible for the fixed volume, and the sphere is the only solid figure possible with this

proviso. Young then argues that there must be other forces arising which limit the volume of liquids and make it so difficult to compress them. He assumes that the particles, whatever the form of the substance they compose (solid, liquid, or vapour), exert a repulsive force which decreases directly as the distance apart of the particles increases. Thus in air and vapours this form is uncontrolled, while in liquids and solids it must be counterbalanced by the attractive force. He supposes the force of cohesion to be nearly or perfectly constant in magnitude throughout the minute distance to which it extends. In all theories the initial assumptions are of the greatest importance, and it may be said to the credit of Young and Laplace that they began on the right lines, for their assumptions agree with the experimental facts of the tendency of vapours to liquefy under great pressure, and for the heat of vaporization to be so large.

It is next necessary to inquire whether the cohesive pressure may be calculated from experiment. Young appears to have solved this problem by noting a curious phenomenon which sometimes happens in the Torricellian method of demonstrating the pressure of the air. A tube sealed at one end and at least one metre in length, is taken and filled with clean dry mercury. On inverting the tube and placing the unsealed end below a mercury surface, the mercury is usually found to fall to a height of about seventy-six centimetres, but occasionally the mercury sticks to the top of the tube by virtue of adhesion and is therefore under the action of a stretching force contrary to that of

cohesion, for the atmosphere can only support a fraction of total column of liquid. Young argued that the liquid resisted forces tending to disrupt it in just the same way as a solid, and he next goes on to find the disruptive force which would have to be applied to a liquid in order to neutralize the force of cohesion. One method of approach is possible from a consideration of the steam pressure which is necessary to exceed the cohesive pressure when ebullition commences. This is exceedingly difficult, for absolutely pure liquid would be necessary as well as absence of agitation. In the case of water, advance along these lines shows that under the requisite conditions boiling will not commence until the steam pressure is of the order of a thousand atmospheres. For boiling to commence, small cavities or bubbles must arise, and these will at first be of the same order as the distance between the particles. Now the pressure in a bubble is directly proportional to the surface tension and inversely proportional to the radius, so that the pressure will have a very high value if the radius is exceptionally small, as in the case under consideration. The problem is much more complicated than the equilibrium of a bubble, for the latter is usually obtained without any reference to the molecular theory or the forces between the molecules, these being included in the surface tension. Young deduced that the cohesive pressure was given by dividing the distance through which the cohesive force extends into three times the surface tension. He gave the value 23,000 atmospheres for the cohesive pressure, and taking the surface tension

as 3 grains per inch, he obtained the result that "the extent of the cohesive force must be limited to about the 250 millionth of an inch." The region in which the cohesive force exists must be taken as the limit of the molecule. Discussing the merits of the investigation, he continues:

"It is not very probable that any error in the suppositions adopted can possibly have so far invalidated this result as to have made it many times greater or less than the truth. Within similar limits of uncertainty, we may obtain something like a conjectural estimate of the mutual distance of the particles of the vapours, and even of the actual magnitude of the elementary atoms of liquids, as supposed to be nearly in contact with each other; for if the distance at which the force of cohesion begins is constant at the same temperature, and if the particles of steam are condensed when they approach within this distance, it follows that at 60° F. the distance of the particles of pure aqueous vapour is about the 250 millionth of an inch; and since the density of this vapour is about one sixty thousandth of that of water, the distance of the particles must be about forty times as great, consequently the mutual distance of the particles of water must be about the ten thousand millionth of an inch."

The great importance of this statement by Young was first emphasized by Lord Rayleigh in 1890, nearly a hundred years after it was made. This magnificent paper of Young's places him as the first natural philosopher to solve the problem of the size of atomic matter, and that he realized the importance of his discovery is seen from a brief extract from a letter to Arago, dated 12th January, 1817:

"I have been reconsidering the theory of capillary attraction, and have at last fully satisfied myself with respect to

the fundamental demonstration of the general laws of superficial contraction, which I have deduced in a manner at once simple and conclusive from the action of a cohesive force extending to a considerable number of particles within a given insensible distance. The solution has very unexpectedly led me to form an estimate, something more than merely conjectural, though not fully demonstrative, of the ultimate atoms of bodies, of water, for instance, about a million of which would occupy a length equal to the diameter of one of the red particles of blood. This, however, you may possibly regard as a mere dream, and you are fully at liberty to do so."

This letter was written twelve years after he first became interested in the theory underlying the action of capillarity, and the period between is of great importance from the injustice he met with at the hands of Laplace, the supreme French mathematician of this decade. He was some twenty years older than Young and had become famous for his analytical solution of the problem of the solar system published in works entitled *Exposition du système du monde* and the *Mécanique celeste*. Laplace was also content to apply his mathematics to some problems in light and to others in capillarity. In the former he adopted Newton's corpuscular theory, and in the latter borrowed freely from Young's work without acknowledging the debt, claiming the ideas as his own. The *Quarterly Review* of 1809 contains a criticism of Laplace's work in optics by Young, who realized the importance of mathematical analysis of the French School, but could not tolerate it when applied to problems which were solved more elegantly from first principles. In one paragraph he states:

“Mr. Laplace has therefore given himself much trouble to prove that coincidence in a particular case, which must necessarily be true in all possible cases. In a person who seems to delight in long calculations, this waste of labour may easily be excused. A Turk laughs at an Englishman for walking up and down a room when he could sit still; but Mr. Laplace may walk about, and even dance, as much as he pleases, in the flowery regions of algebra, without exciting our smiles, provided that he does no worse than return to the spot from which he set out; but when, in the rapidity of his motion, his head begins to turn, it is time for the spectators to think of their own safety.”

He further adds:

“We complain also, on national grounds, of an unjustifiable want of candour, in not allotting to the observations of different authors their proper share of originality.”

Thus in spite of Laplace's great brilliancy he appears to have borrowed right and left from those philosophers whom he considered practically unknown. He made mistakes with three famous men, viz. Legendre, Fourier and Young. In criticizing Laplace's contributions to the subject of capillarity Dr. Young first points out the remarkable similarity to his own efforts, which, as we have already intimated, were published a year before Laplace brought his results before the Institute of France, while he glories in the fact that there was no necessity to introduce a single mathematical symbol. The harvest from Young's work is more extensive than that of Laplace, who went so far as to assert that his superior skill in mathematical technique showed inaccuracies in Newton's treatment. This cannot be allowed when it is realized that Young

obtains identical results, so that Newton's mistakes did not depend on any deficiency in his mathematical acquirements. Hence, although Laplace's service to science was very great, it has been the unhappy lot of posterity to point out his want of candour and to lay bare his true character. He resembled the Vicar of Bray in his loyalty to whatever party held the reins of political power and so survived the Revolution, the Napoleonic era and the Restoration. His ambitions were realized, for he eventually became a marquis, but he forgot those who had assisted him to fame from the most obscure of beginnings.

We have mainly stressed the application of Young's genius to the solution of the size of the ultimate atoms, or more truly the region through which atomic forces extend, but it must be remembered that this really was one application of his theory of cohesion, and there are many other results in the theory of equal importance. Thus we find the equilibrium of different liquids in contact discussed, and the reason given for the spreading of one liquid over another, for example, oil over water, as well as the angle at which a liquid meets a solid. In the case of water and glass this angle is zero, and there is a tendency for the water to spread in an excessively thin layer over the surface of the glass. Many of these problems have been tackled successively by different investigators since the time of Young, and their methods are certainly not so difficult to understand, but his labours in this subject will always be a source of wonder and an inspiration to those who seek to render intelligible the intricacies of the works of nature.

CHAPTER XV

RESEARCHES IN THE EGYPTIAN HIEROGLYPHICS

THERE are many people to-day who find considerable relaxation and pleasure in solving crossword puzzles. Thomas Young found in the writings of the Ancient Egyptians problems of a similar nature which occupied part of his leisure from 1814 to the end of his life.

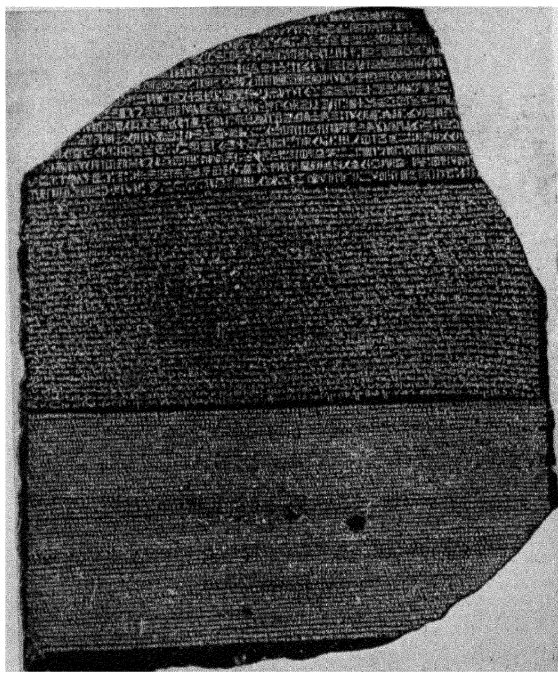
The early part of the nineteenth century saw the introduction of many important historical documents from Egypt to France and England, and many attempts were made to decipher the records, which were mainly inscriptions on stone or papyri from mummy-cases. Probably the most important discovery was made by the French in 1799 at Rosetta, here a black basalt pillar inscribed with a decree of Ptolemy Epiphanes in three characters—hieroglyphics, demotic and Greek, of which the first two are respectively the so-called sacred letters and the letters of the country. The stone was transferred to the British Museum after the capitulation of the French in Egypt. Dr. Young first turned his attention to deciphering these records in 1814, when in the November of that year he published a conjectural translation of the second of these inscriptions of the Rosetta Stone. Some idea

of the difficulties of the problem may be realized when investigation revealed the fact that the early part of the first inscription was destroyed, and that many portions of the Greek were mutilated. Thanks to the labours of those distinguished Greek scholars, Porson and Heyne, the third inscription was restored with very little ground for error, and the last paragraph indicated that the three inscriptions, as far as was possible, expressed the same decree.

At this stage it will be convenient to examine the problem as it confronted Young, and his remarks upon it, and we are fortunate in having at our disposal fairly full details in the third volume of his works edited by John Leitch. He first compared the Greek and second inscription, groups of characters in the latter being obviously recognizable as the equivalents of Alexander and Alexandria. It was not very difficult to find the conjunctions and the words which were repeated most frequently, such as "Ptolemy" and "king." He then says:

"Having thus obtained a sufficient number of common points of subdivision, we may next proceed to write the Greek text over the enchorial (demotic), in such a manner that the passages ascertained may all coincide as nearly as possible; and it is obvious that the intermediate parts of each inscription will then stand very near to the corresponding passages of the other."

After observing that the inscription must be read from right to left, he proceeds to the difficulties encountered in using this translation as a key to that of the first inscription. Young therefore pasted upon parchment the corresponding parts of



THE ROSETTA STONE.

the two first inscriptions, having been provided with copies of engravings through the kindness of the Antiquarian Society, and then compared them as in his solution of the last pair of inscriptions.



... ΣΤΕΡΕΟΥΛΙΘΟΥ ΤΟΙΣ ΤΕΙΕΡΟΙΣ ΚΑΙ ΕΓΧΩΡΙΟΙΣ ΚΑΙ ΕΛΛΗΝΙΚΟΙΣ ΓΡΑΜΜΑΙΣ

[illegible]

ΚΑΙ ΣΤΗΣΑΙ ΕΝ ΕΚΑΣΤΩ ΤΩΝ ΤΕ ΠΡΩΤΩΝ ΚΑΙ ΔΕΥΤΕΡΩΝ



۱۰ ربیع الثانی ۱۳۵۷ھ / ۱۷ مارچ ۱۹۳۷ء



● 文 49-1 及び 49-2 の調査結果を、図 2 のように示す。

[illegible]

112. 20 14 26 10 11 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32 33 34 35 36 37 38 39 40 41 42 43 44 45 46 47 48 49 50 51 52 53 54 55 56 57 58 59 60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 95 96 97 98 99 100 101 102 103 104 105 106 107 108 109 110 111 112 113 114 115 116 117 118 119 120 121 122 123 124 125 126 127 128 129 130 131 132 133 134 135 136 137 138 139 140 141 142 143 144 145 146 147 148 149 150 151 152 153 154 155 156 157 158 159 160 161 162 163 164 165 166 167 168 169 170 171 172 173 174 175 176 177 178 179 180 181 182 183 184 185 186 187 188 189 190 191 192 193 194 195 196 197 198 199 200 201 202 203 204 205 206 207 208 209 210 211 212 213 214 215 216 217 218 219 220 221 222 223 224 225 226 227 228 229 230 231 232 233 234 235 236 237 238 239 240 241 242 243 244 245 246 247 248 249 250 251 252 253 254 255 256 257 258 259 260 261 262 263 264 265 266 267 268 269 270 271 272 273 274 275 276 277 278 279 280 281 282 283 284 285 286 287 288 289 290 291 292 293 294 295 296 297 298 299 300 301 302 303 304 305 306 307 308 309 310 311 312 313 314 315 316 317 318 319 320 321 322 323 324 325 326 327 328 329 330 331 332 333 334 335 336 337 338 339 340 341 342 343 344 345 346 347 348 349 350 351 352 353 354 355 356 357 358 359 360 361 362 363 364 365 366 367 368 369 370 371 372 373 374 375 376 377 378 379 380 381 382 383 384 385 386 387 388 389 390 391 392 393 394 395 396 397 398 399 400 401 402 403 404 405 406 407 408 409 410 411 412 413 414 415 416 417 418 419 420 421 422 423 424 425 426 427 428 429 430 431 432 433 434 435 436 437 438 439 440 441 442 443 444 445 446 447 448 449 450 451 452 453 454 455 456 457 458 459 460 461 462 463 464 465 466 467 468 469 470 471 472 473 474 475 476 477 478 479 480 481 482 483 484 485 486 487 488 489 490 491 492 493 494 495 496 497 498 499 500 501 502 503 504 505 506 507 508 509 510 511 512 513 514 515 516 517 518 519 520 521 522 523 524 525 526 527 528 529 530 531 532 533 534 535 536 537 538 539 540 541 542 543 544 545 546 547 548 549 550 551 552 553 554 555 556 557 558 559 560 561 562 563 564 565 566 567 568 569 570 571 572 573 574 575 576 577 578 579 580 581 582 583 584 585 586 587 588 589 590 591 592 593 594 595 596 597 598 599 600 601 602 603 604 605 606 607 608 609 610 611 612 613 614 615 616 617 618 619 620 621 622 623 624 625 626 627 628 629 630 631 632 633 634 635 636 637 638 639 640 641 642 643 644 645 646 647 648 649 650 651 652 653 654 655 656 657 658 659 660 661 662 663 664 665 666 667 668 669 670 671 672 673 674 675 676 677 678 679 680 681 682 683 684 685 686 687 688 689 690 691 692 693 694 695 696 697 698 699 700 701 702 703 704 705 706 707 708 709 710 711 712 713 714 715 716 717 718 719 720 721 722 723 724 725 726 727 728 729 730 731 732 733 734 735 736 737 738 739 740 741 742 743 744 745 746 747 748 749 750 751 752 753 754 755 756 757 758 759 760 761 762 763 764 765 766 767 768 769 770 771 772 773 774 775 776 777 778 779 780 781 782 783 784 785 786 787 788 789 790 791 792 793 794 795 796 797 798 799 800 801 802 803 804 805 806 807 808 809 810 811 812 813 814 815 816 817 818 819 820 821 822 823 824 825 826 827 828 829 830 831 832 833 834 835 836 837 838 839 840 841 842 843 844 845 846 847 848 849 850 851 852 853 854 855 856 857 858 859 860 861 862 863 864 865 866 867 868 869 870 871 872 873 874 875 876 877 878 879 880 881 882 883 884 885 886 887 888 889 890 891 892 893 894 895 896 897 898 899 900 901 902 903 904 905 906 907 908 909 910 911 912 913 914 915 916 917 918 919 920 921 922 923 924 925 926 927 928 929 930 931 932 933 934 935 936 937 938 939 940 941 942 943 944 945 946 947 948 949 950 951 952 953 954 955 956 957 958 959 960 961 962 963 964 965 966 967 968 969 970 971 972 973 974 975 976 977 978 979 980 981 982 983 984 985 986 987 988 989 990 991 992 993 994 995 996 997 998 999 1000 1001 1002 1003 1004 1005 1006 1007 1008 1009 1010 1011 1012 1013 1014 1015 1016 1017 1018 1019 1020 1021 1022 1023 1024 1025 1026 1027 1028 1029 1030 1031 1032 1033 1034 1035 1036 1037 1038 1039 1040 1041 1042 1

14. $\frac{1}{x^2} = x^{-2}$ $\frac{d}{dx} x^{-2} = -2x^{-3} = -\frac{2}{x^3}$

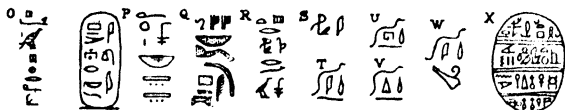


FIG. 10.—Young's arrangement of the last line of the Rosetta Stone.


As illustration (Fig. 10) the last line of the Rosetta Stone, as treated in this way by Young, is added. The results he obtained were of great importance, and he summarizes them as follows:

"In thus comparing the demotic with the sacred characters, we find many coincidences in their forms, by far too accurate to be compatible with the supposition that the demotic could be of a nature purely alphabetical. It is evident, for example, that the demotic characters for a *diadem*, an *asp* and *everlasting*, are immediately borrowed from the sacred. But this coincidence can certainly not be traced throughout the inscriptions; and it seemed natural to suppose that alphabetical characters might be interspersed with hieroglyphics, in the same way that astronomers and chemists of modern times have often employed arbitrary marks, as compendious expressions of the objects which were most frequently to be mentioned in their respective sciences. But no effort, however determined and persevering, had been able to discover any alphabet, which could fairly be said to render the inscription in general at all like what was required to make its language intelligible Egyptian; although most of the proper names seemed to exhibit a tolerable agreement with the forms of letters indicated by Mr. Akerblad; a coincidence, indeed, which might be found in the Chinese, or in any other character not alphabetical, if they employed words of the simplest sounds for writing compound names."

Akerblad was a distinguished researcher in ancient languages, resident in Paris, and he had shown that the proper names mentioned were analysable by means of an alphabet, but he could make no further progress with it. It was at this point in the inquiry that Young made his discovery that the demotic writings were traceable back to the hieroglyphic or sacred characters, the former being the hieroglyphics adapted to a running hand. As time went on the scribes would make the latter more facile until marks were necessary to indicate the object more distinctly, and signs were also

necessary to cope with changes in dialect, just as we find a change from Chaucerian to present-day English. Naturally the sacred writings would remain unchanged, so that at the time of the Rosetta inscription (195 B.C.) there would only be the faintest resemblance between the native or demotic and its original prototype. These conclusions were mentioned in letters dated 1816, which were written to the Archduke John of Austria, who had become interested in the subject when visiting England, and also to Akerblad, and they were later published in Young's article "Egypt," which he contributed to the *Encyclopedia Britannica*.

Dr. Young was greatly assisted in his discoveries connected with the hieroglyphics by the publication of copies of most of the existing manuscripts and papyri, which were nearly all funeral scrolls, being representations of the scenes and stages up to the last judgment of a life hereafter commonly believed in by the Egyptians. His work showed that these beliefs had been handed down until the time of classical authors such as Diodorus, and he verified their records so well as to bring to light the generic relationship of the demotic to the sacred characters. Prior to this he had come to the conclusion that all proper names in the hieroglyphics were sur-

rounded by a ring or frame as shown ,

and that the words therein were necessarily phonetic, He supports this by a reference to the Chinese,

where the symbol  (kon) placed to the left

of a group of three characters 𐀓 se, 𐀔 te,

𐀕 lung, change the several meanings,

magistrate, to obtain, and dragon, to the English word "strong." He, moreover, asserted that these rings were around the names of persons recorded on the monuments founded by them, and not the Gods in whose honour they had been built, and in the case of a female the name was accompanied by a semicircle above an oval. The hieroglyphics were commonly supposed to be addressed to the eye only, and it was a great step forward when Young advanced the hypothesis that the characters expressing the proper names under special circumstances were addressed to the ear instead, i.e. they resembled the case quoted above. It was found by Champollion, a contemporary French investigator in the same subject, that Young's assumption was a little too wide and that the rings were confined to the names and titles of royalty only, while the phonetic nature of the hieroglyphics was applied elsewhere too. Prior to 1821 Champollion had followed Akerblad in his attempts at interpreting the various inscriptions, and had made little headway, although his knowledge of the history and customs of the Egyptians as well as of their modern language was unrivalled. The result was a publication in that year entitled *De l'Écriture Hieratique des anciens Égyptiens*, in which Champollion advances the conclusions that the hieroglyphics had been

modified to form a running hand through various phases until we reach the enchorial, and that the hieroglyphics were the signs of things and not the signs of sounds, i.e. not phonetic. It will be seen that in the first conclusion he had been anticipated by Young by at least seven years, and in the second he was wrong. In the subsequent year he completely withdrew his previous statement that the hieroglyphics were not phonetic, and followed every one of the hypotheses advanced by Dr. Young,

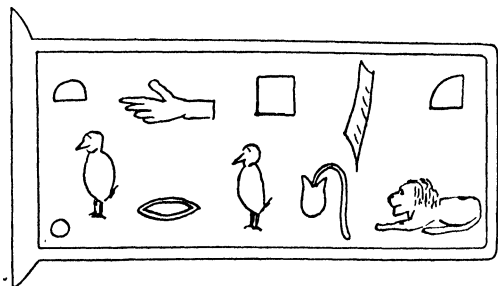


FIG. 11.—CLEOPATRA.

except the correction with regard to proper names, without any acknowledgment, and he even claimed the new change of attitude as his own discovery. There appeared in 1824 his *Précis du Système Hiéroglyphique*, in which he successfully enlarged upon the principles employed by Dr. Young, and corrected the hypothesis on the phonetic characters. Again he was fortunate in receiving an engraving containing the name of Cleopatra in hieroglyphics and Greek, which helped him to arrive at the correct

use of phonetic characters. Dr. Young had two royal names to base his deductions upon, namely,

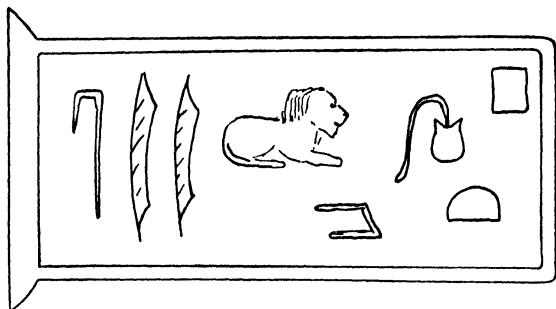


FIG. 12.—PTOLEMY.

Ptolemy and Bernice, in both of which there were possible ambiguities. We shall consider the three

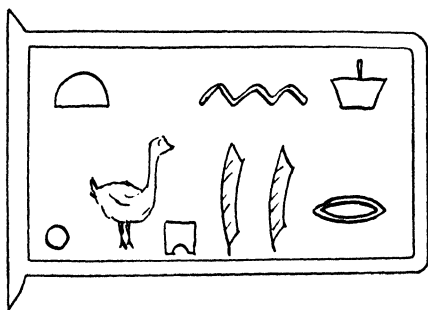


FIG. 13.—BERNICE.

names as indicating the solutions by Young and Champollion.

In the first case Cleopatra is represented in the

diagram. Starting from right to left of the lion, flower, feather and parallelogram, three are repeated in Ptolemy, and may be identified as the letters L, O, E and P. The bird must be A, and this leaves the quadrant of the circle, the open hand, the mouth are phonetic, representing the sounds of K, T and R respectively. The distinguishing marks of the female are also discernible. It rarely happens that there is no ambiguity as in Cleopatra, for consider the case of Bernice, who was the wife of Ptolemy Soter, and is found mentioned in an inscription on the ceiling of the temple at Karnak. Champollion with the knowledge he had gained from interpreting Cleopatra recognized the mouth as being R, the basket to be B, the wavy line to be N, the footstool to be K, and the goose to be S, equivalent to BRNIKS. According to Dean Peacock, the choice which Young was allowed according to the knowledge he had of the subject was one of twelve:

Bereniken	Breniken	Briniken	Brnikn
Berenikes	Brenikes	Brinikes	Brniks
Berenike	Brenike	Brinike	Brnik

And whereas Young adopted the first and ninth, Champollion adopted the eleventh.

Dr. Young's contribution may be summarized as follows:

(1) He was the first to grasp the idea of a phonetic principle in the reading of the Egyptian hieroglyphics.

(2) He was the first to apply this principle to deciphering the inscription.

(3) Dr. Young independently discovered and

first applied successfully the alphabetic hieroglyphics, and

(4) The oval or cartouche designation of a proper name.

(5) He recognized the semicircle surmounting an oval as indicating a goddess.

Champollion (1790-1832) corrected and enlarged Young's list of alphabetic Egyptian characters, and he further formulated the accepted system of grammar and general decipherment used up to the present. His success was largely due to his excellent knowledge of Coptic—the language of the first Egyptians to embrace Christianity—which helped him to find the phonetic values of many syllabic signs as well as to interpret the pictorial characters.

Hence we may conclude that the merit of priority belongs to Dr. Young despite the extravagant claims of the French contemporaries of Champollion in these matters. Difficulties also arose since Dr. Young published anonymously until 1823, and Champollion gave no credit to anyone except himself for any discovery in these realms.

BIBLIOGRAPHY AND REFERENCES

PUBLICATIONS BY DR. YOUNG

1. *A Course of Natural Philosophy and the Mechanical Arts.* 1807.
2 vols. 4to. Excellent for reference, but difficult to obtain.
- 1A. New Edition published in 1845, edited by Professor Kelland.
2 vols. 8vo. Print rather small.
2. *An Introduction to Medical Literature, including a System of Practical Nosology.* 1813. 8vo.
- 2A. New Edition with Essay on Palpitations added. 1823.
3. *A Practical and Historical Treatise on Consumptive Diseases.* 1815. 8vo.
4. *Letter of Canova and Memoirs of Visconti on the Elgin Marbles.*
Translated 1816. 8vo.
5. *An Account of the Recent Discoveries in Hieroglyphical Literature and Egyptian Antiquities.* 1823. 8vo.
6. *Elementary Illustrations of the Celestial Mechanics of Laplace.* 1821. 8vo.
7. *Enchorial Egyptian Dictionary*, appended to the Egyptian Grammar by Henry Tatton (q.v.). 1830.

REFERENCES TO HIS LIFE

- (A) Gurney's *Memoir.* 1831. Difficult to obtain—deals with Young's character very fully, and gives a full list of his publications.
- (B) Pettigrew's *Life of Young in His Medical Portrait Gallery.* 1840. This considers Young's labours as a Physician and also gives a brief account of his life and character along with a complete list of all his published papers.
- (C) Peacock's *Life of Young.* 1855. Excellent for reference.

REFERENCES TO HIS WORKS AND WRITINGS

1. *Miscellaneous Works of Dr. Thomas Young*, by Peacock and Leitch. 3 vols. 1854. These contain all the published

154 BIBLIOGRAPHY AND REFERENCES

- papers and correspondence; vol. 3 deals with Hieroglyphical Researches.
2. Bence Jones's *Royal Institution* gives an interesting and excellent account of Young's work in connection with the Royal Institution.
 3. Brief comments on Young are to be found in the standard histories of science, e.g. *Whewell's History of the Inductive Sciences*, *Barrow's Sketches of the Royal Society*, or Rouse Ball's *History of Mathematics*.
 4. *The Rosetta Stone*. Printed by the order of the trustees of the British Museum.

APPENDIX

THE PRODUCTION OF INTERFERENCE COLOURS IN SOAP FILMS

THE general disposition of the apparatus is shown in Fig. 14. It is the most satisfactory arrangement, the colours being projected on to a screen by means of an achromatic lens. White light from a lantern is first passed through a

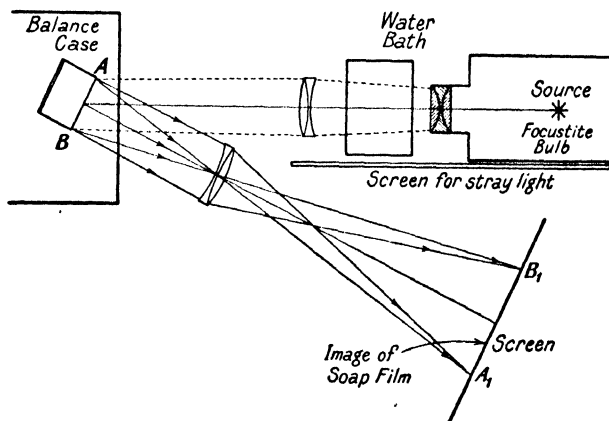


FIG. 14.

trough of water containing alum and is then incident upon the film nearly normally. The film itself (AB) is formed on a shallow glass trough about 3 inches in diameter, and care must be taken to make the rim smooth. A little black

paper at the bottom of the trough prevents reflection from the glass base. The film is placed in a glass case to shield it from draughts and temperature changes. The lens which casts the real image of the film (A_1B_1) is about 12 inches focal length and the screen is 4 feet away. In carrying out the experiment the vessels used must be scrupulously clean, and it is best to leave them to soak in a mixture of strong sulphuric acid and potassium di-chromate and then rinsing in tap water.

The results with a solution of sodium oleate (25 grs./litre) and the effects of adding ammonia and glycerine are as follows:

1. The pure solution gives horizontal bands after $1\frac{1}{2}$ to 2 mins. The black film then appears and this is surmounted by the colours in the order shown in fig. 5 (page 104). The average life is about 4 mins., but cooling the film lengthens the life.

2. Adding a few drops of strong ammonia causes the bands to be formed with great rapidity, but the film has a life of only 2 mins. The colours are very delicate and change quickly as the film thins under gravity.

3. The general effect of glycerine is to toughen the film. The solution is first diluted with its own volume of distilled water and then a few c.c.'s of glycerine are added and well mixed. The resulting film is quite stable with a life of easily half an hour, but the bands are now thinner and colour filters are really best to bring them out. Too much glycerine makes the film streaky.

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